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Air Force Human Systems Integration Improved Performance Research
Integration Tool (IMPRINT Pro) Maintenance Model Enhancements

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711th Human Performance Wing
Human Performance Integration Directorate
(711 HPW/HP)

# Air Force Human Systems Integration Improved Performance Research Integration Tool (IMPRINT Pro) Maintenance Model Enhancements

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September 2009



**Air Force Research Laboratory**
**711th Human Performance Wing**
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September 2009
711 Human Performance Wing
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Technical Report

# Air Force Human Systems Integration Improved Performance Research Integration Tool (IMPRINT Pro) Maintenance Model Enhancements

by

Timothy Bagnall, Karl Hart

ABSTRACT

This report summarizes a yearlong effort devoted to the improvement of a human performance simulation of the flightline maintenance and sortie generation process for the Air Force 711th Human Performance Wing. The simulation is known as the Air Force Human Systems Integration Improved Performance Research Integration Tool Maintenance Model – or the AF HSI IMPRINT Mx Model. The effort described here is the continuation of a previous effort that analyzed Air Force operational metrics and identified human performance determinants of mission success including environmental, safety, and occupational health considerations of the F-15C Eagle weapon system. This effort used IMPRINT, a free for government use task-network human performance simulation tool for analyzing Warfighter-System interaction. This report describes the latest version of the AF HSI IMPRINT Mx Model and the enhancements implemented by the project team that improved the original simulation. The enhancements include the addition of five new weapon systems (C-17 Globemaster III, CV-22 Osprey, F-15E Strike Eagle, MQ-1 Predator, and MQ-9 Reaper), dynamic charting of operational metrics, an intuitive graphical user interface for Air Force analysts, and the incorporation of a physiological stressor for modeling fatigue. Through the ability to adjust various independent variables (e.g., number of available maintenance specialists, number of aircraft, mission flying time), the simulation provides a means to analyze the contribution of human performance to Air Force mission generation and operational metrics (e.g., sortie generation rate, administrative delay time, flying schedule effectiveness) and assess the environmental, safety, and occupational risks associated with generating Air Force missions.

*Human nature is the only science of man; and yet has been hitherto the most neglected.*

- David Hume

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- TSgt Joseph Hall; Hurlburt Field
- SSgt Jeremy Stephens; Hurlburt Field

# 1 EXECUTIVE SUMMARY

This report discusses the work accomplished during a yearlong Modeling and Simulation Information Analysis Center (MSIAC) effort to continue the investigation of the relationship between human performance and Air Force (AF) Major Command (MAJCOM) operational metrics. In the previous year, the AF 711$^{th}$ Human Performance Wing and contractor team developed a flightline maintenance and mission generation process simulation of the F-15C Eagle using the Army's Improved Performance Research Integration Tool (IMPRINT). IMPRINT, also referred to as IMPRINT Pro, is a simulation software tool designed specifically for analyzing the interaction between the Warfighter and system to understand total system performance. The F-15C simulation developed in the previous year allowed the user to set up experimental designs whereby hypothetical operational scenarios were described through various independent variables. Results of the model, the dependent variables/operational metrics, revealed to the user how the scenario unfolded so assessments could be made of how the human maintainer impacted the achieved results. Figure 1-1 shows a schematic of the experimental design of the simulation.

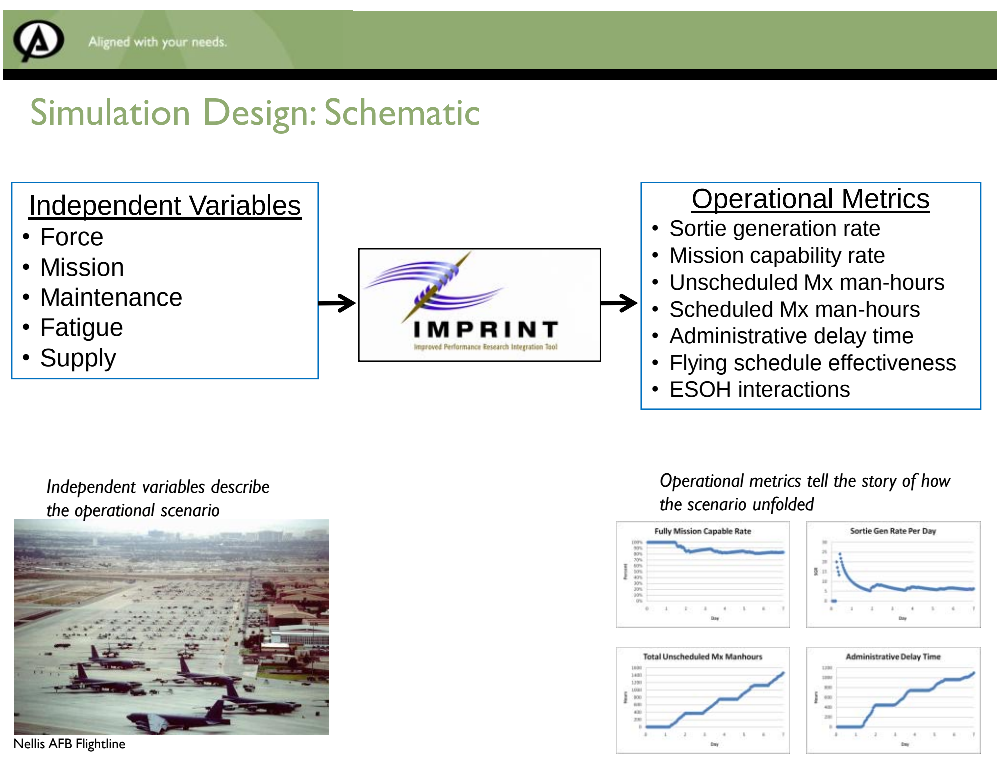


Figure 1-1. Simulation design schematic.

In this effort, the team implemented several enhancements to the original F-15C flightline and mission generation simulation. One improvement was the addition of five new weapon systems to the simulation: C-17 Globemaster III, CV-22 Osprey, F-15E Strike Eagle, MQ-1 Predator, and MQ-9 Reaper. Additionally, the team added the ability to model Warfighter fatigue through the incorporation of Sleep Activity Fatigue Task Effectiveness (SAFTE) theory developed by Dr. Steven Hursh, Ph.D. of Johns Hopkins University School of Medicine in the work he did for the Department of Defense and others. Another addition, dynamic charting, allows the user to review operational metrics as the simulation executes and understand in real simulation time how the scenario unfolds. And the last enhancement, the addition of an intuitive graphical user interface (GUI), provides the user the ability to describe mission scenarios without having to know the intricacies or technicalities of the IMPRINT task-network modeling tool.

# 2 INTRODUCTION

In FY 2008, the 711th Human Performance Wing (HPW), Alion Science and Technology (Alion), and Thomas Associates Incorporated, developed a human performance simulation of the flightline maintenance and mission generation process of the F-15C Eagle for the purpose of investigating how the role of the Air Force (AF) maintainer impacts the operational metrics that are used to diagnose the health of the AF's weapon systems. (Please refer to technical report for contract GS10F0161L/FA8900-07-F-0008 "Advisory and Assistance Services in support of Human Systems Integration in MAJCOM Operational Metrics and Environment, Safety, and Occupational Health Assessments Using Process Sequence Models" for more information on the preceding yearlong effort). Being well received, the AF 711th HPW chose to continue the effort by enhancing the capabilities of the simulation and including five additional weapon systems. To complement the F-15C Eagle and provide a broad suite of weapon systems mirroring the AF's capabilities, Alion added the following weapon systems to the human performance simulation: C-17 Globemaster III, CV-22 Osprey, F-15E Strike Eagle, MQ-1 Predator, and MQ-9 Reaper. In addition to the five new weapon systems, Alion improved the usability of the simulation by developing an intuitive interface for designing mission scenarios and reviewing results, and incorporating a physiological stressor to determine the impact of maintainer fatigue from extended wakefulness. The team also added a method – called dynamic charting to review the operational metrics graphically.

For a concise introductory document regarding the AF HSI IMPRINT Pro Mx Model covering its background and intended uses, please refer to Section 7.7 in the appendices. Section 7.7, "AF HSI IMPRINT Pro Maintenance Model Introductory Flier," can be printed and shared with colleagues as a quick and easy read.

## 2.1 Topic Development

Section 3, "Methods, Assumptions, and Procedures," is the heart of this report where the simulation is discussed and instructions on how and why an AF analyst would employ its capabilities. Section 3 begins with a short description of the simulation software used by the project team. The report continues by describing how the team researched the technical details of the flightline maintenance and mission generation process of the five new weapon systems including visiting AF bases and establishing Subject Matter Expert (SME) contacts. Section 3.4 discloses the task-network design of the flightline maintenance and mission generation process and includes technical details of how the simulation functions. Section 3.5 complements the described task-network design by presenting the GUI and instruction on how to set up and run an analysis. Section 3.6 lists the simplifying assumptions assumed by the project team to reduce the scope of the effort to match the level of funding provided and deliver the AF with a value-added tool for investigating the impacts of human performance on MAJCOM operational metrics.  Section 4.1 reviews all the custom reports that the simulation writes after execution (i.e. the operational metrics/dependent variables/results).

## 2.2 Intended Audience

The specific intended audience of this report is HSI advocates to the systems engineering process, HSI Practitioners, AF personnel seated in the 711th Human Performance Wing (HPW), AF operational metric analysts, and AF maintenance production supervisors.  However, the report is not limited to the aforementioned audience and may be found pertinent to a wide range of audiences interested in human performance modeling, AF operational metrics, or AF capabilities based planning.

# 3 METHODS, ASSUMPTIONS, AND PROCEDURES

## 3.1 IMPRINT Pro Simulation Software

The U.S. Army Research Laboratory, Human Research & Engineering Directorate developed the Improved Performance Research Integration Tool (IMPRINT) Pro to support Manpower and Personnel Integration (MANPRINT) and Human Systems Integration (HSI). IMPRINT Pro is a dynamic, stochastic, discrete event network modeling tool designed to help assess the interaction of Warfighter and system performance throughout the system lifecycle from concept and design to field testing and system upgrades. IMPRINT is available for official government use at no charge to the user (e-mail imprint-info@arl.army.mil for more information to obtain a license).

IMPRINT Pro can be used to help set realistic system requirements; to identify soldier-driven constraints on system design; and to evaluate the capability of available manpower and personnel to effectively operate and maintain a system under environmental stressors. IMPRINT Pro is also used to target Warfighter performance concerns in system acquisition; to estimate Soldier-centered requirements early, and to make those estimates count in the decision making process. As a research tool, IMPRINT Pro incorporates task analysis, workload modeling, performance shaping and degradation functions and stressors, and embedded personnel characteristics data.

In previous versions, IMPRINT, as it was named, focused solely on Army missions. In its latest version, IMPRINT Pro is a joint service tool with the capability to examine Army, Navy, Air Force, and Marine systems.

IMPRINT Pro is used to model both crew and individual performance. For some analyses, workload profiles are generated so that crew-workload distribution and individual-system task allocation can be examined. In other cases, maintainer utilization is assessed along with the resulting system availability. Also, using embedded algorithms, IMPRINT Pro models the effects of personnel characteristics, training frequency, and environmental stressors on the overall system performance. Manpower requirements estimates can be generated for a single system, a unit, or an entire service. The output from IMPRINT Pro can be used as the basis for estimating manpower lifecycle costs.

IMPRINT Pro is a powerful analysis tool that can be used to:

- Set realistic system requirements
- Identify future manpower and personnel constraints

- Evaluate operator and crew workload (auditory, cognitive, gross motor, fine motor, speech, tactile, and visual)
- Test alternate system-crew function allocations
- Assess required maintenance man-hours
- Assess performance during extreme climate conditions (from extreme cold to extreme heat)
- Examine operator performance as a function of personnel aptitude characteristics and training frequency
- Evaluate the effects of whole body vibration on Warfighter performance
- Identify areas of the system under evaluation to focus test and evaluation resources
- Quantify human system integration risks to mission performance to support milestone review
- Estimate life-cycle cost of system design
- Represent humans in federated simulations
- Conduct force projections of service personnel in future years by various categories
- Evaluate the impact of sea state on Warfighters operating on marine vessels

## 3.2 Installing the AF HSI IMPRINT Mx Model Plug-in

Installation of the AF HSI IMPRINT Mx model requires placing three .dll files within your IMPRINT root directory. (To obtain a copy of IMPRINT, contact imprint-info@arl.army.mil).These .dll files are referred to as "plug-ins" and provide IMPRINT with enhanced capabilities. Figure 3-1 shows the three required plug-ins necessary for executing an Air Force maintenance model.


**Figure 3-1. The three plug-in files necessary for executing the AF HSI IMPRINT Mx model.**

*MAAD.Plugins.AirForceHSI.dll*

This plug-in provides a majority of the capabilities discussed in this report from the graphical user interface, reading Excel data files, and writing Excel reports.

*ARL.Plugins.SAFTE.dll*

This plug-in provides the capability to consider Warfighter fatigue. This report presents more information regarding the SAFTE plug-in in Section 7.6 on page 93.

*System.Windows.Forms.DataVisualization.dll*

This plug-in is necessary to have the dynamic charting capability where operational metrics are charted during simulation run time.

## 3.3 Subject Matter Expert Data Collection and Air Force Base Site Visits

With the introduction of five new weapon systems to the AF HSI IMPRINT Mx Model, the project team visited several Air Force bases to collect data from subject matter experts (SMEs) to clarify the intricacies of the flightline maintenance process. Because the project team deemed that the F-15E Strike Eagle was similar enough in nature to the F-15C Eagle, the team did not visit an F-15E Air Force Base (AFB). Instead the project team established a relationship with an F-15E SME via e-mail. The team used a questionnaire – found in the Flightline Maintenance Process Questionnaire appendix in Section 7.1, to solicit initial information from SMEs. Additionally, because the project team deemed that the flightline maintenance process of the C-17 Globemaster III was relatively simple when compared to the other new weapon systems, an approach similar to the one taken for the F-15E Strike Eagle was taken where a relationship with an SME was formed using e-mail. With those two qualifiers in mind, the team decided to focus its visits on the flightlines of some of the more challenging weapon systems, namely the CV-22 Osprey, MQ-1 Predator, and MQ-9 Reaper. A trip to Hurlburt Field in early February of 2009 to tour the CV-22 Osprey flightline established a strong contact that provided invaluable help for the modeling of the CV-22 Osprey. Similarly, a trip to Creech AFB in late April 2009 to tour the MQ-1 Predator and MQ-9 Reaper flightline established several contacts providing helpful details.

## 3.4 Task-Network Design

This section of the report discusses the design of the AF HSI IMPRINT Mx Model task-network. A task-network, for the purpose of simulation, is the organization and description of a system into discrete events, or tasks, that are performed, usually chronologically, to achieve a specific goal or objective. In this case the flightline maintenance and mission generation process is a system designed to support the AF's concept of operations of global power, reach, and vigilance. The maintenance process ensures aircraft are ready and available to conduct various missions that provide a wide range of capabilities to achieve the necessary peacetime and wartime effects as pursued by the Department of Defense (DoD). Figure 3-2, on page 9, shows the top-level of the AF HSI Mx Model task-network. Each of the six weapon systems included in the simulation use this exact configuration. IMPRINT Pro uses pink ovals to represent tasks and grey rectangles to represent networks. IMPRINT Pro refers to networks as functions within its framework so the report will henceforth use function instead of network. (The authors bring up this semantic point regarding network vice function because literature has historically used the term task-network). Generally, a human performance modeler uses a task in IMPRINT Pro to represent a discrete event or action performed by a human, computer, or combination of the two. The modeler can assign a task with a mean duration, standard deviation, mean accuracy, and other model variables to emulate human behavior or represent actions performed by automation. A function is simply a grouping of similar tasks or functions for the purpose of hierarchical organization. For instance, function 61, "Mission Preparation," seen in Figure 3-2, holds several tasks performed by the flightline maintenance team for preparing an aircraft for an upcoming mission.

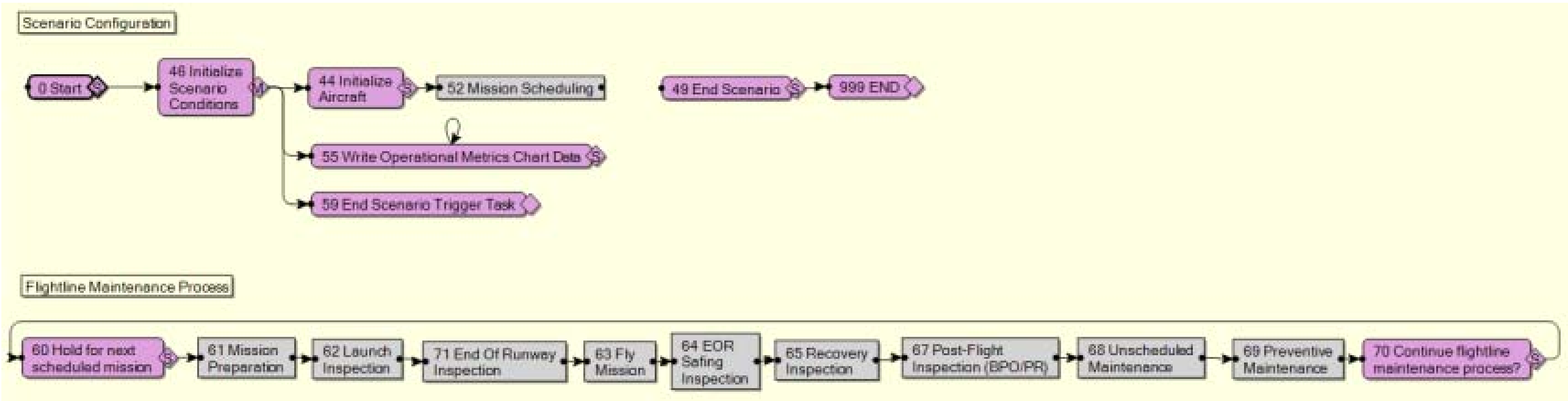


Figure 3-2. The top-level of the AF HSI Mx Model task-network.

*Note: IMPRINT Pro assigns a unique number to each task and function as a means for differentiation. The assigned numbers have no bearing on the execution order of the tasks and functions.*

The top-level of the task-network consists of two distinct areas organized into two rows: i) Scenario Configuration and ii) Flightline Maintenance Process.

i. Scenario Configuration

The scenario configuration row (see Figure 3-3) holds five tasks and a single function (excluding the “0 Start” and “999 END” IMPRINT Pro system tasks that are required for all IMPRINT Pro simulations to allow the simulation engine to run). These five tasks and single function are for administrative purposes and do not represent human behavior. Together, these five tasks cause the simulation to execute the scenario as specified by the AF analyst (see Section 3.5 for scenario specification using the graphical user interface).

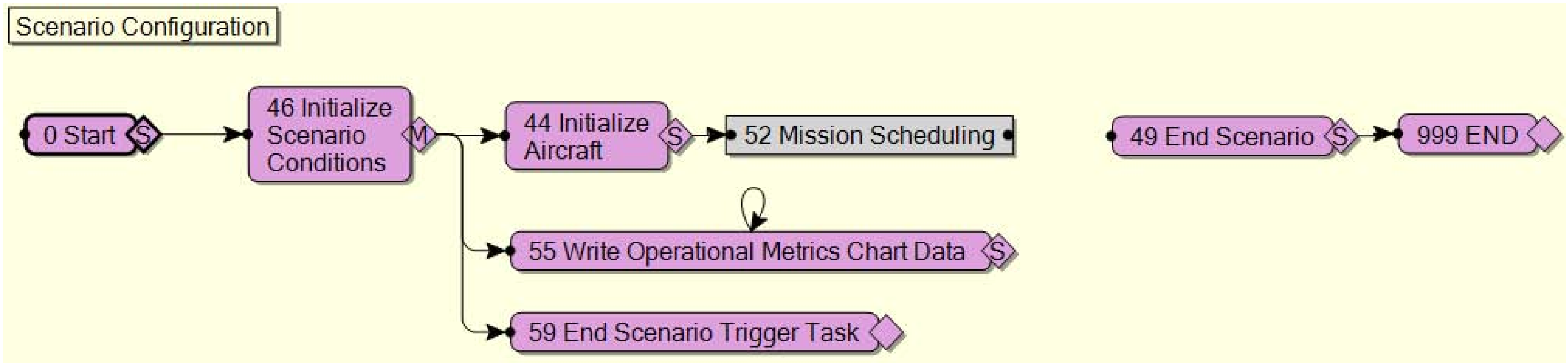


Figure 3-3. The task-network scenario configuration row.

When running the AF HSI Mx Model, the first task to execute is Task 0, ‘start.” Task 0 is mandatory for all IMPRINT Pro task-network operation models and is used by the simulation engine as the simulation starting point. The next task to execute is Task 46, “Initialize Scenario Conditions.” Task 46 contains several macros – a collection of software programming code – used to gather the initial values of variables specified by the user in the scenario definition interface and import Maintenance Data Collection System (MDCS) maintenance statistics (see Section 3.5.3), from Microsoft Excel. After Task 46 has finished, Tasks 44, 55, and 59 execute simultaneously. Task 44, “Initialize Aircraft,” causes the exact number of weapon systems specified by the user in the define scenario interface to appear in the flightline maintenance process at Task 60, “Hold for next scheduled mission.” Task 55, “Write Operational Metrics Chart Data” executes repeatedly over the course of the simulation – every 1 hour of simulated time - and is used to capture essential statistics for the operational metrics reports. The data captured is written to several different .csv Excel report files (see Section 4.1) that can be reviewed and charted once the simulation has finished executing. Task 59, “End Scenario Trigger Task,” is used to schedule the termination of the scenario and thus the simulation. Task 59’s duration lasts exactly the length specified by the user in the define scenario interface. When this scenario length has transpired, Task 59 will finish executing and then start Task 49, “End Scenario” where concluding information describing the scenario is captured and written to the reports. Within Function 52, “Mission Scheduling,” a lone task exists for the sake of scheduling what time aircraft begin the flightline maintenance process and for how long the aircraft conduct missions for the entire scenario.

ii. Flightline Maintenance Process

The flightline maintenance process row (Figure 3-4) holds the essential functions and tasks that represent the flightline maintenance team supporting the mission generation process. Tasks within these nine functions represent the heart of the simulation where human maintainers perform the duties assigned to them of inspecting and maintaining aircraft.

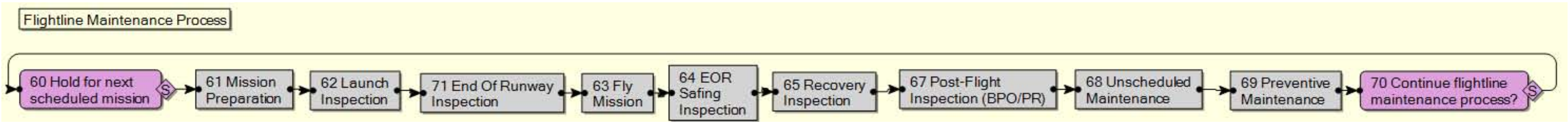

Figure 3-4. The task-network flightline maintenance process row.

Each aircraft in the specified scenario begins its existence at Task 60, “Hold for next scheduled mission.” For instance, if the AF analyst specified that there are 12 weapon systems in the Force GUI (Section 3.5.1), 12 aircraft entities would appear in Task 60 waiting until a scheduled mission commences causing one or more aircraft to begin the flightline maintenance process in Function 61, “Mission Preparation.”

Figure 3-5 shows an example of a 12 aircraft scenario at simulation time zero. Notice above Task 60 the number 12 that indicates the amount of aircraft in the scenario. In simulation parlance, these 12 aircraft that flow through the simulation are also referred to as entities. An entity is a conceptual object that travels through a task-network (e.g. in an interstate simulation for evaluating toll booths, the vehicles would be considered entities). Also in Figure 3-5, notice that administrative tasks 44, 55, and 59 are highlighted blue - meaning that they are currently executing - and above them have a number 1. In this case, the number 1 does indicate an entity, but it is solely for administrative reasons and not to represent an aircraft entity.

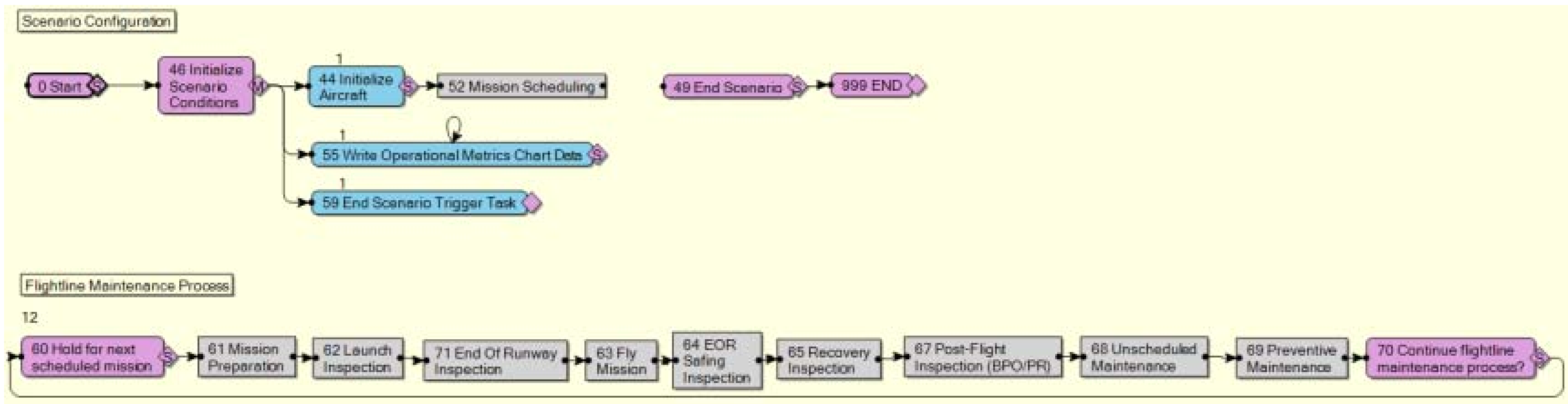

Figure 3-5. Simulation snapshot at time zero for a 12 aircraft scenario.

All the aircraft entities will exist within the Flightline Maintenance Process available to conduct missions until the scenario ends. Aircraft flow through this process starting with Task 60, next moving to Function 61, “Mission Preparation,” and continuing all the way to Task 70, “Continue flightline maintenance process?” After finishing Task 70, an aircraft will return to Task 60 and wait until another mission is scheduled.

Figure 3-6 shows a snapshot of the simulation to illustrate how the aircraft entities appear as they flow through the task-network. In this figure, two aircraft are undergoing a basic post-flight and preflight inspection (BPO/PR), two aircraft are preparing for an impending mission, and eight aircraft are waiting for an upcoming mission.

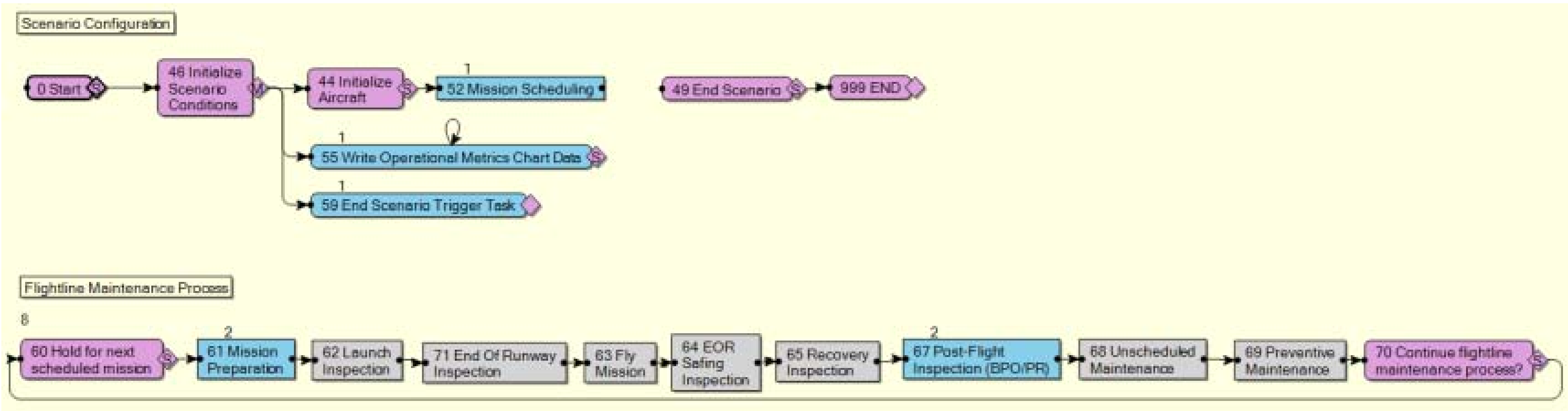


Figure 3-6. Simulation snapshot at time greater than zero.

The next few sub-sections discuss each function within the Flightline Maintenance Process in detail.

### 3.4.1 Function 61, "Mission Preparation."

Figure 3-7 shows the six tasks (excluding the start and end system tasks) of the Mission Preparation function. The blue and red hexagons in the figure, called the uplink and downlink respectively, show the IMPRINT user how entities enter and exit functions of the task-network. For instance, an aircraft would enter the Mission Preparation function through Task 60, "Hold for next scheduled mission," and an aircraft would exit the Mission Preparation function by continuing to Function 62, "Launch Inspection."

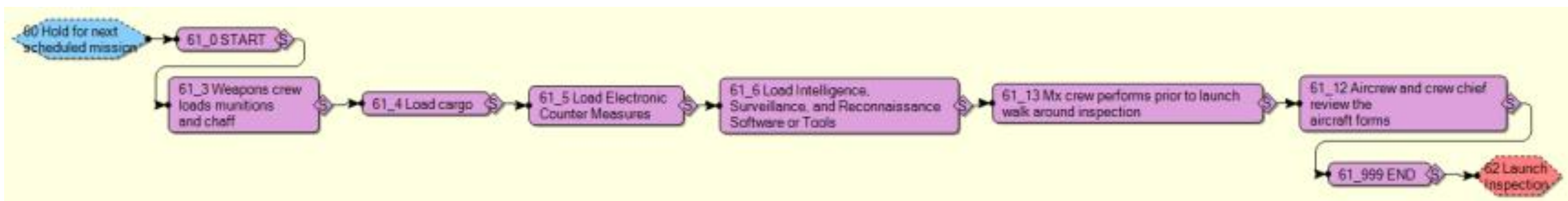

Figure 3-7. Function 61, "Mission Preparation."

The six tasks shown in Figure 3-7 describe maintenance activities performed by the flightline maintenance team to prepare an aircraft for conducting a mission. Depending on the weapon system, not all of the tasks will actually be performed by maintenance personnel. For instance, when running a simulation of the F-15C Eagle there will be no cargo or intelligence, surveillance and reconnaissance software to load. When an aircraft entity representing an F-15C Eagle flows through the Mission Preparation function, the simulation will execute these tasks (61_4 and 61_5), however no time will be accrued nor will any manpower be devoted. Any task that is not applicable to a particular weapon system will not affect the outcome of the simulation.

The names of the tasks are intuitive by design and explain the activities performed by the maintenance team. What is important to know concerning each task is the time (or duration), manning requirement, and any environment, safety, and occupational health (ESOH) interactions. The next few figures will go into depth concerning these three task settings.

Task Duration

Figure 3-8 shows a snapshot of the IMPRINT interface for entering task time using model code. Two radio buttons are available: one for using built in mathematical distributions (Use Distributions) and another for using a custom expression (Use Expression). In this case, and for all the tasks of the simulation, the "Use Distributions" option is invoked. In the figure, a rectangular distribution with a mean of 2 hours (2 * 3600 seconds) and minimum of 1.8 hours (1.8 x 3600 seconds) is used to simulate the duration it takes weapon technicians to load chaff and flare on the C-17 Globemaster III. The "ApplyFatigueAdjustment" text in the stressor applies Dr. Steven Hursh's Sleep Activity Fatigue and Task Effectiveness (SAFTE) algorithm for representing the effectiveness of humans under extended wakefulness. More information on the SAFTE algorithm is found in the appendix in Section 1.-676854895.

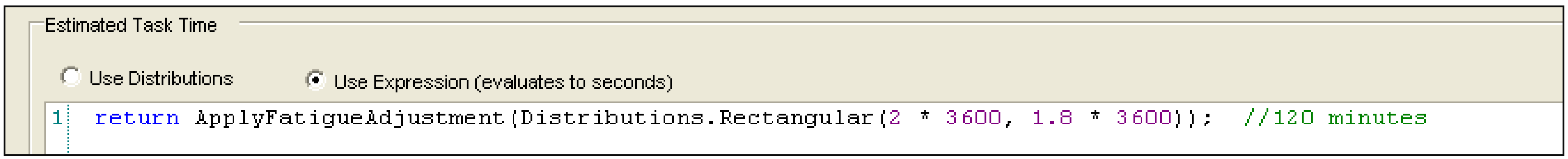


Figure 3-8. C-17 Globemaster III task time for the weapons crew loading munitions and chaff.

Manning Requirement

Figure 3-9 shows a snapshot of the IMPRINT interface for entering the required manpower to perform the task. Every task has a release condition, beginning effect, and ending effect. A release condition specifies what conditions must be true before the task will execute. The beginning effect specifies what occurs before the task executes and the ending effect specifies what occurs after the task has executed.

Release Condition

```
if (numAvailableWeapons > 1)  //chaff and flare are most likely not added each mission
{
    return true;
}
else
{
    return false;
}
```

Beginning Effect

```
numAvailableWeapons-=2;  //employ weapon crew

time[Entity.Tag] = CalcDayAndHour(Clock); // capture start time

ESOH_SafPrim+=2; //weaponry
ESOH_HealthSec+=2; //lifting

```

Ending Effect

```
numAvailableWeapons+=2;  //release weapon crew

weaponsRoutineMxMHtime+=2 * Entity.Duration;  //capture routine Mx time

HSI.PrintToFile(Model.RunNumber, "ACevents_" + Entity.Tag + ".csv", Model.RunNumber + "," + time[Entity.Tag]
```

Figure 3-9. C-17 Globemaster III manning requirement for the weapons crew loading munitions and chaff.

Release Condition

In line one of the release condition in Figure 3-9, the software programming code “if (numAvailableWeapons > 1)” asks whether there is more than one weapon technician available to perform the task. The simulation uses the variable numAvailableWeapons as a method to keep track of the amount of available weapon technician manpower. The manning requirement to load chaff on the C-17 Globemaster III is two weapon technicians. If there are at least two weapon technicians the task will execute (return true); if not, the task will wait until other technicians become available (return false). Weapon technicians may also be busy performing end-of-runway inspections (Function 71) and end-of-runway safing inspections (Function 64). The green text “//chaff and flare are most likely not added each mission” is used as a software programming comment to give the user a description of the code to be executed. In this case, the note lets the user know that chaff and flare is typically not added to the C-17 Globemaster III each cycle of the flightline maintenance process. This is due to the fact that the C-17 Globemaster III does not expend these protective elements often.

Beginning Effect

In line one of the beginning effect in Figure 3-9, the software programming code “numAvailableWeapons-=2” is used to employ two weapon technicians for the installation of chaff and flare. (Changing this code to read “-=4” would employ four weapon technicians and so on. When altering this code, make sure that the number requested in the release condition matches the number employed in the beginning effect and released in the ending effect). By employing two weapon technicians to perform this task, the available number of weapon technicians to perform other tasks is decreased by two.

Line two of the beginning effect, “time[Entity.Tag] = CalcDayAndHour(Clock);” captures the scenario clock time at the beginning of the task. This beginning time is captured for use in writing to the custom reports so that the user can review when tasks throughout the scenario started.

Line five and six of the beginning effect, capture any ESOH interactions of the maintainer that take place during the execution of the task. In this case, “ESOH_SafPrim+=2;” and “ESOH_HealthSec+=2;” capture two primary safety interactions of the two weapon technicians loading weaponry and two secondary occupational health interactions of the two weapon technicians lifting heavy materials.

Ending Effect

In line one of the ending effect in Figure 3-9, the programming code “numAvailableWeapons+=2” is used to release two weapon technicians after the installation of chaff and flare has been completed. This code releases the two weapon technicians so that they are free to perform other work of the flightline maintenance process. (Changing this code to read “+=4” would release four weapon technicians and so on. When altering this code, make sure that the number requested in the release condition matches the number employed in the beginning effect and released in the ending effect).

Line three of the ending effect, “weaponsRoutineMxMHtime+=2 * Entity.Duration;” is used to capture the running total of routine maintenance man-hours performed by the weapon technicians. Since two weapon technicians perform this task, Entity.Duration, a system variable that captures the duration of the task, is multiplied by two and added to the weaponsRoutineMxMHtime variable. A task is considered routine maintenance when it is not found in the official “-6” (pronounced “dash six”) maintenance manual for that particular weapon system. When a task is found in the “-6,” it is considered scheduled maintenance and a similar line of code will capture the running total of scheduled maintenance for the persons performing the task. For instance, the F-15C Eagle has an official launch inspection in its “-6” performed by a crew chief and maintenance technician. The ending effect for this task of the F-15C Eagle would capture this scheduled maintenance for the crew chief and maintenance technician.

Line five of the ending effect, “HSI.PrintToFile(Model.RunNumber, "ACevents_" + Entity.Tag + ".csv", Model.RunNumber + "," + time[Entity.Tag] + ",Weapons crew attaches chaff and flare,0,0,0,2," + Math.Round(Entity.Duration/60, 0));” (not entirely shown in Figure 3-9) is used to write a custom report to a comma separated values (.csv) file that the user may review in Microsoft Excel after the simulation has been completed. For each aircraft in the scenario, this line of code captures the simulation run number (Model.RunNumber), the time the task began (time[Entity.Tag]), and the duration of the task (Entity.Duration). Also captured is a note about the task that was performed - “Weapons crew attaches chaff and flare” – and the manning required to perform the task – “0,0,0,2.” The format of the “0,0,0,2” portion of the note is aircrew, crew chiefs, maintenance technicians, and weapon technicians. The “0,0,0,2” indicates that two weapon technicians performed the task. When opening the .csv file in Excel, it will have descriptive column headers in the first row so that the user can comprehend what is captured by line five of the ending effect (see Table 3-1).

Table 3-1. Example IMPRINT Pro output .csv file with descriptive column headers.

| Run | Day | Hour | Event | Aircrew | Crew Chiefs | Mx Techs | Weapons | Duration(Mins) |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 0:00 | Weapons crew attaches chaff and flare | 0 | 0 | 0 | 2 | 116 |

Table 3-2 shows the task times, manning, and environment, safety, and occupational health (interactions) for the C-17 Globemaster III mission preparation function. The remainder of this section includes tables with task timing, manning and ESOH interactions for other functions of the task-network model for the C-17 Globemaster III. For other weapon systems, the way of reviewing this information is through the IMPRINT Pro file itself.

Table 3-2. Task times, manning, and ESOH interactions for the C-17 Globemaster III mission preparation function.

| Task Name | Time (Minutes) | Aircrew | Crew Chief | Mx Techs | Weapon Techs | Environment | Safety (primary) | Safety (secondary) | Occ Health (primary) | Occ Health (secondary) |
|---|---|---|---|---|---|---|---|---|---|---|
| Weapons crew loads munitions and chaff | 108 - 132 | 0 | 0 | 0 | 2 | 0 | 2 | 0 | 0 | 2 |
| Load cargo | 50 - 170 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Load electronic counter measures | N/A | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Load intelligence, surveillance, and reconnaissance software or tools | N/A | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Maintenance crew performs prior to launch walk around inspection | 45 - 60 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Aircrew and crew chief review the aircraft forms | 15 - 30 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

### 3.4.2 Function 62, "Launch Inspection."

Table 3-3 shows the three tasks that make up the "Launch Inspection" function. This function as shown in Figure 3-10 involves the maintenance team performing an inspection as the aircraft starts its systems, the maintenance team marshalling the aircraft to the taxiway, and the aircrew taxiing to the end of runway location.

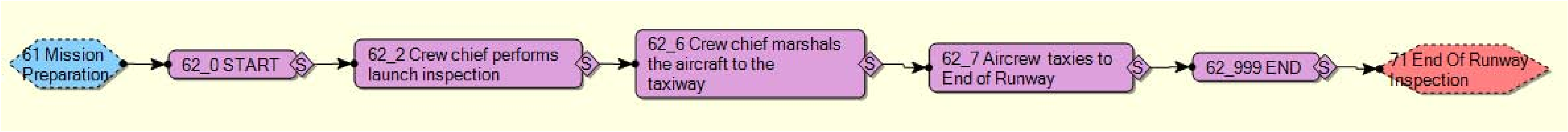


Figure 3-10. Function 62, "Launch Inspection."

Table 3-3. Task times, manning, and ESOH interactions for the C-17 Globemaster III launch inspection function.

| Task Name | Time (Minutes) | Aircrew | Crew Chief | Mx Techs | Weapon Techs | Environment | Safety (primary) | Safety (secondary) | Occ Health (primary) | Occ Health (secondary) |
|---|---|---|---|---|---|---|---|---|---|---|
| Crew chief performs launch inspection | 35 - 65 | 0 | 1 | 2 | 0 | 0 | 2 | 1 | 2 | 1 |
| Crew chief marshals the aircraft to the taxiway | 5 - 10 | 0 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| Aircrew taxies to End of Runway | 10 - 20 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

3.4.3 Function 71, “End of Runway Inspection.”

Figure 3-11 shows the single task that makes up the “End of Runway Inspection” function. The task within this function involves inspecting the aircraft and the munitions system just prior to launch. Not all aircraft of the included weapons systems perform this task due to differing flightline maintenance procedures. For instance, the Globemaster III does not have the maintenance crew perform this function as seen in Table 3-4.

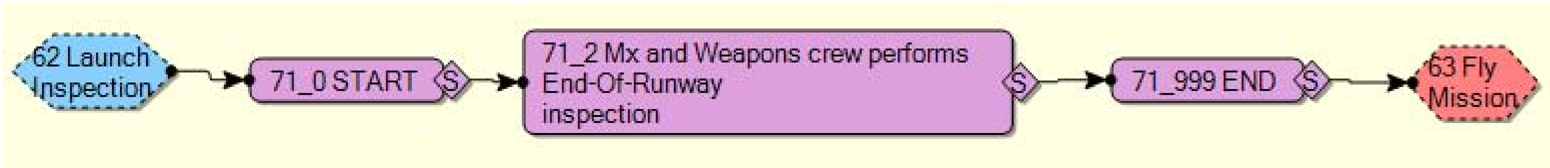


Figure 3-11. Function 71, "End of Runway Inspection."

Table 3-4. Task times, manning, and ESOH interactions for the C-17 Globemaster III end of runway inspection function.

| Task Name | Time (Minutes) | Aircrew | Crew Chief | Mx Techs | Weapon Techs | Environment | Safety (primary) | Safety (secondary) | Occ Health (primary) | Occ Health (secondary) |
|---|---|---|---|---|---|---|---|---|---|---|
| Mx and Weapons crew performs end-of-runway inspection | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

3.4.4 Function 63, "Fly Mission."

Figure 3-12 shows the four tasks that make up the "Fly Mission" function. This function begins with the aircrew launching the aircraft from the runway in Task 63_11. From here, depending on the probabilities of an abort or an attrite assigned by the user, the simulation will continue to one of these three tasks: Task 63_16, "Aircrew flies mission;" Task 63_12, "Aircrew aborts mission;" and Task 63_13, "Aircrew attrite." If the weapon system and aircrew are lost in battle, Task 63_13 will execute writing to a report to let the user know that the aircraft was lost. If the weapon system suffers from an aborted mission, Task 63_12 will execute. If the weapon system flies a normal mission, Task 63_16 will execute. Following a normal or aborted mission, the aircrew and weapon system will touch down and land the aircraft in Task 63_14. Since the aircrew performs all four tasks in this function, no maintenance manpower is employed and no ESOH hazards are encountered by the maintenance team as seen in Table 3-5.

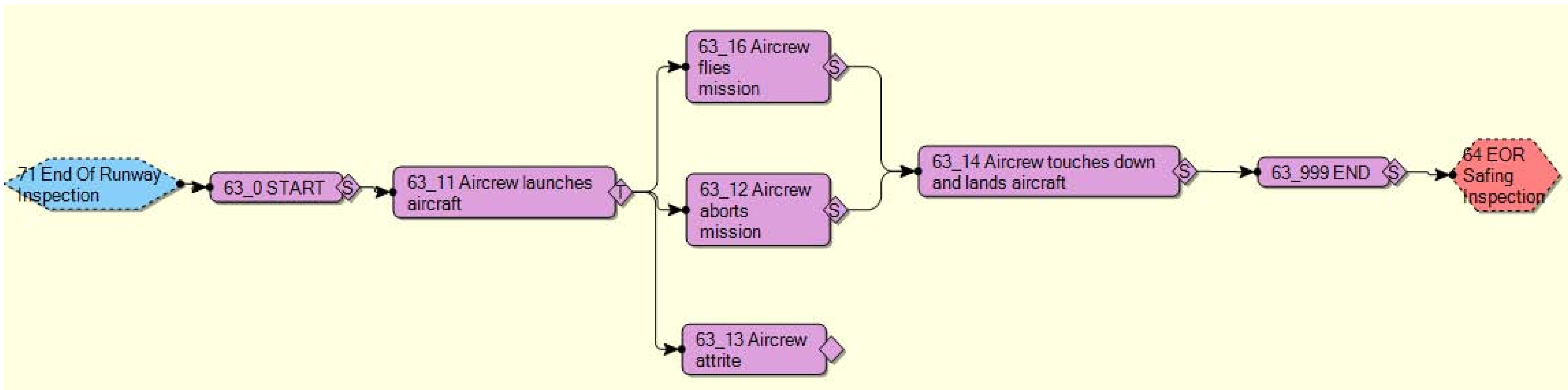


Figure 3-12. Function 63, "Fly Mission."

Table 3-5. Task times, manning, and ESOH interactions for the C-17 Globemaster III fly mission function.

| Task Name | Time (Minutes) | Aircrew | Crew Chief | Mx Techs | Weapon Techs | Environment | Safety (primary) | Safety (secondary) | Occ Health (primary) | Occ Health (secondary) |
|---|---|---|---|---|---|---|---|---|---|---|
| Aircrew launches aircraft | 0.5 - 1 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Aircrew flies mission | Set by user | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Aircrew aborts mission | Set by user | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Aicrew attrite | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Aircrew touches down and lands aircraft | 0.5 - 1 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

### 3.4.5 Function 64, "End of Runway Safing Inspection."

Figure 3-13 shows the two tasks that make up the "End of Runway Safing Inspection" function. In this function, the maintenance crew meets the weapon system at an end of the runway location and inspects the aircraft and munitions system to ensure that it is safe before it continues to its parking location. After the aircraft has been 'safed," it taxies to its parking location where another maintenance team is awaiting its arrival. Not all aircraft of the modeled weapon systems have a safing task performed as seen in Table 3-6.


Figure 3-13. Function 64, "End of Runway Safing Inspection."

Table 3-6. Task times, manning, and ESOH interactions for the C-17 Globemaster III end of runway safing inspection function.

| Task Name | Time (Minutes) | Aircrew | Crew Chief | Mx Techs | Weapon Techs | Environment | Safety (primary) | Safety (secondary) | Occ Health (primary) | Occ Health (secondary) |
|---|---|---|---|---|---|---|---|---|---|---|
| Mx crew performs End-Of-Runway safing inspection | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Aircrew taxies to parking spot | 5 - 10 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

3.4.6 Function 65, "Recovery Inspection."

Figure 3-14 shows the two tasks that make up the "Recovery Inspection." After arriving at the parking spot, the maintenance crew performs a recovery inspection in Task 65_3 to receive the aircraft after it has flown a mission. Additionally, if any cargo needs to be unloaded it is conducted in Task 65_4. No time is included for the unloading of cargo as seen in Table 3-7 for the Globemaster III as it was included in the duration estimate for the recovery inspection by SMEs. A note is provided in the AF HSI IMPRINT Mx Model that explains this caveat of the C-17 Globemaster III model.


Figure 3-14. Function 65, "Recovery Inspection."

Table 3-7. Task times, manning, and ESOH interactions for the C-17 Globemaster III recovery inspection function.

| Task Name | Time (Minutes) | Aircrew | Crew Chief | Mx Techs | Weapon Techs | Environment | Safety (primary) | Safety (secondary) | Occ Health (primary) | Occ Health (secondary) |
|---|---|---|---|---|---|---|---|---|---|---|
| Mx Crew Performs Recovery Inspection | 45 - 60 | 0 | 1 | 2 | 0 | 0 | 2 | 1 | 2 | 1 |
| Unload Cargo | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

3.4.7 Function 67, "Post Flight (BPO/PR) Inspection."

Figure 3-15 shows the three tasks that make up the "Post Flight (BPO/PR) Inspection" function. Task 67_1 is where the maintenance team performs the Basic Post Flight/Preflight (BPO/PR) Inspection. The BPO/PR is an official "-6" scheduled inspection that is performed between missions. Depending on whether the user has chosen to model Contingency/Combat (C/C) inspections, Task 67_2 will execute if the aircraft has reached its C/C flight hour interval. For instance, if the user has specified that the F-15C Eagle receives a C/C inspection every 25 flight hours, when an F-15C exceeds this 25 hour threshold in the simulation, Task 67_2 will execute and the maintenance crew will perform a C/C inspection. After finishing the BPO/PR and possibly the C/C inspection, the fuels crew will refuel the aircraft in Task 67_4.

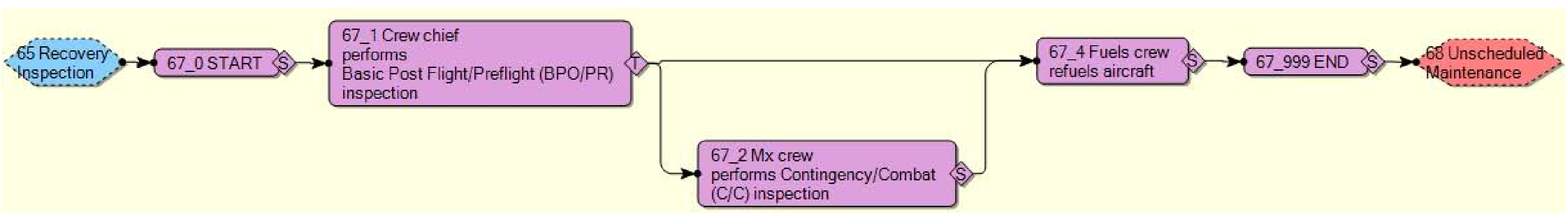


Figure 3-15. Function 67, "Post Flight (BPO/PR) Inspection."

Table 3-8. Task times, manning, and ESOH interactions for the C-17 Globemaster III post flight (BPO/PR) inspection function.

| Task Name | Time (Minutes) | Aircrew | Crew Chief | Mx Techs | Weapon Techs | Environment | Safety (primary) | Safety (secondary) | Occ Health (primary) | Occ Health (secondary) |
|---|---|---|---|---|---|---|---|---|---|---|
| Crew chief performs Basic Post-Flight/Preflight (BPO/PR) inspection | 150 - 180 | 0 | 1 | 1 | 0 | 2 | 2 | 0 | 2 | 0 |
| Mx crew performs Contingency/Combat (C/C) inspection | N/A | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Fuels crew refuels aircraf | 30 - 55 | 0 | 1 | 2 | 0 | 1 | 3 | 0 | 3 | 0 |

### 3.4.8 Function 68, "Unscheduled Maintenance."

Below, Figure 3-16 and Figure 3-17 show the eight tasks that make up the "Unscheduled Maintenance" function. Because of this function's large size in IMPRINT's graphical user interface, the function is split among the two figures so the task names are legible. The function begins with Task 68_1 where the simulation determines whether any components of an aircraft necessitate repair by the maintenance team. If no components need repairing, the simulation continues with Task 68_8, "No unscheduled Mx necessary." If unscheduled maintenance is necessary for one or more components, the simulation will continue with Task 68_11 where it determines if the broken component requires a spare part to be ordered. You will note that no task link connects Task 68_1 with Task 68_8 or Task 68_11 in Figure 3-16. This is due to sophisticated modeling programming code that was necessary for handling more than one failed component simultaneously. When more than one component necessitates a repair, multiple entities will be created at Task 68_11 that represent each of those components. Here the simulation of the flightline maintenance process departs from a single entity representing an aircraft and briefly transforms into multiple entities representing the components that need repairing of an aircraft. Once all the repairs for an aircraft have been completed, these multiple entities merge back into the original aircraft entity in Task 68_6. But before merging back into one aircraft entity, a broken component goes through supply and repair tasks. If a replacement part is necessary for the repair, the simulation will execute Task 68_2 where the wait time for the particular part is calculated. Once the supply part has been delivered or after determining no supply part was necessary, the simulation continues with Task 68_4 where the maintenance crew size for the repair is determined. If there are enough maintenance technicians available to make the repair, the simulation will execute Task 68_9 in which the failed component is corrected. The last task to execute in the “Unscheduled Maintenance” function is Task 68_12, “Capture NMC Stats.” This task summarizes information about how long an aircraft waited for receiving any unscheduled maintenance and receiving any ordered supply parts. Using this waiting time information, the task keeps track of the non mission capable rate due to supply, maintenance, or both.

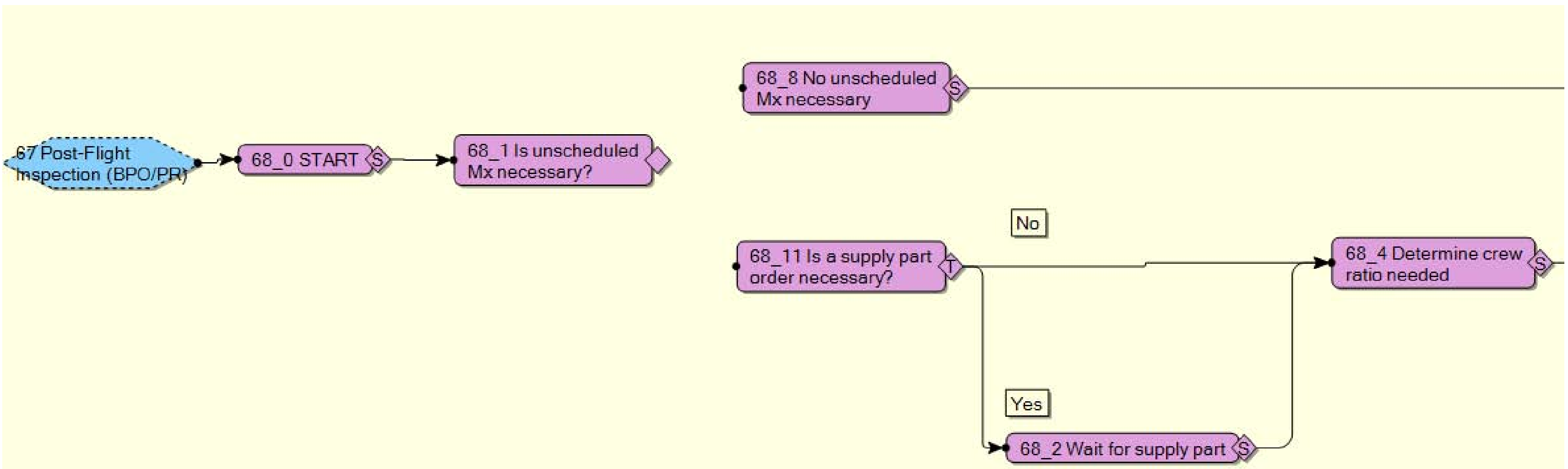


Figure 3-16. Function 68, "Unscheduled Maintenance" Part I.

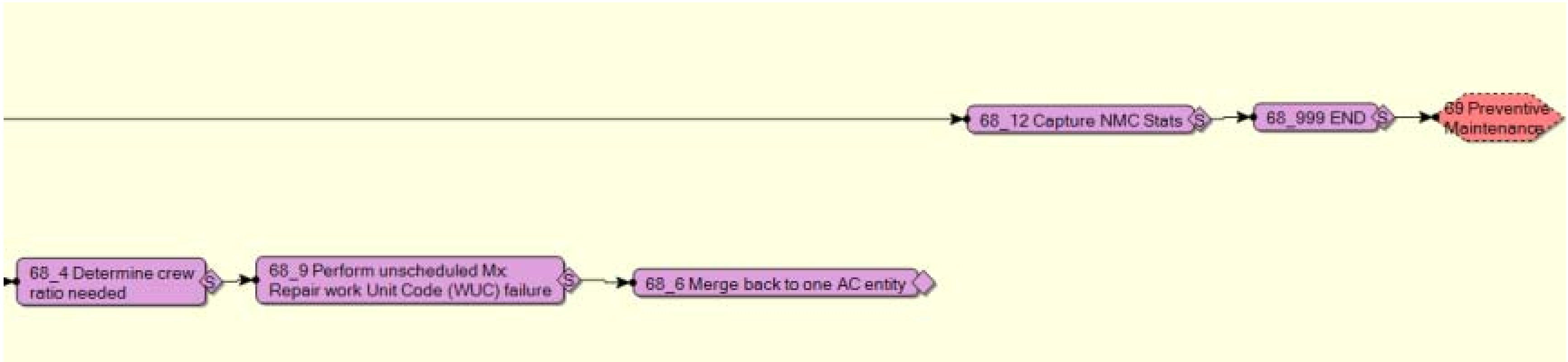


Figure 3-17. Function 68, "Unscheduled Maintenance" Part II.

Table 3-9. Task times, manning, and ESOH interactions for the C-17 Globemaster III unscheduled maintenance function.

| Task Name | Time (Minutes) | Aircrew | Crew Chief | Mx Techs | Weapon Techs | Environment | Safety (primary) | Safety (secondary) | Occ Health (primary) | Occ Health (secondary) |
|---|---|---|---|---|---|---|---|---|---|---|
| Is unscheduled maintenance necessary? | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| No unscheduled Mx is necessary | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Is a supply part order necessary? | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Wait for supply part | Set by user | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Determine crew ratio needed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Perform unscheuled Mx: Repair Work Unit Code (WUC) failure | TBD | 0 | 0 | TBD | 0 | TBD | TBD | TBD | TBD | TBD |
| Merge back to one AC entity | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Capture NMC Stats | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

### 3.4.9 Function 69, "Preventive Maintenance."

Figure 3-18 shows the single task the makes up the "Preventive Maintenance" function. Currently, Task 69_1 serves only as a placeholder for when detailed information about the performance of preventive maintenance can be added to the simulation for each weapon system. As such, no maintenance manning demand, task duration transpires, or ESOH hazard interactions occur when the simulation executes Task 69_1. Without the inclusion of major preventive maintenance inspections (e.g. Hourly Post-Flight, Preventive, Home Station Check), the simulation does not accurately capture operational metrics with simulating for longer than a few weeks; however, with additional funding and resources the inclusion of major preventive maintenance tasks would enhance the results of the simulation and allow for scenario durations longer than a few weeks.

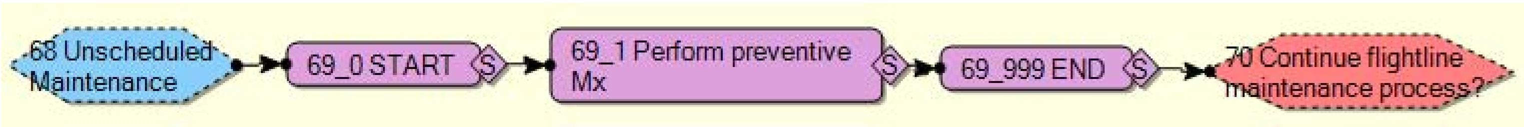

Figure 3-18.  Function 69, "Preventive Maintenance."

### 3.5 AF HSI IMPRINT Mx Model Graphical User Interface

This section of the report discusses the Graphical User Interface (GUI) the AF analyst uses to modify the independent variables of the model before executing a simulation.

Before viewing the GUI, an AF HSI analysis must be added to the IMPRINT Pro Analysis Tree. To add an AF HSI analysis, right click on the "Analyses" folder in the "Analysis Tree" and select "New HSI Analysis" (see Figure 3-19).

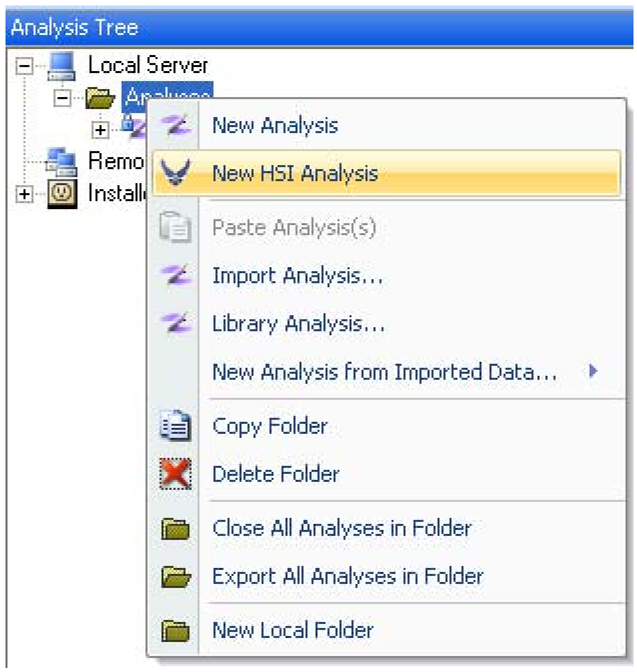


Figure 3-19. Adding a new HSI Analysis to the IMPRINT Pro "Analysis Tree."

Once a new HSI analysis has been added to the IMPRINT Analysis Tree, six missions, representing the six weapon systems of the AF HSI Mx Model, appear in the analysis tree (see Figure 3-20).

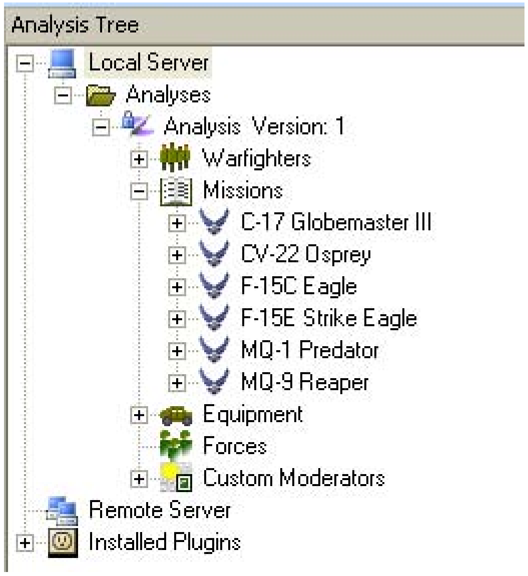


Figure 3-20. A new HSI Analysis with the six weapon systems as missions.

To view the AF HSI Mx Model GUI, double-click on any of the six mission nodes (see Figure 3-21).

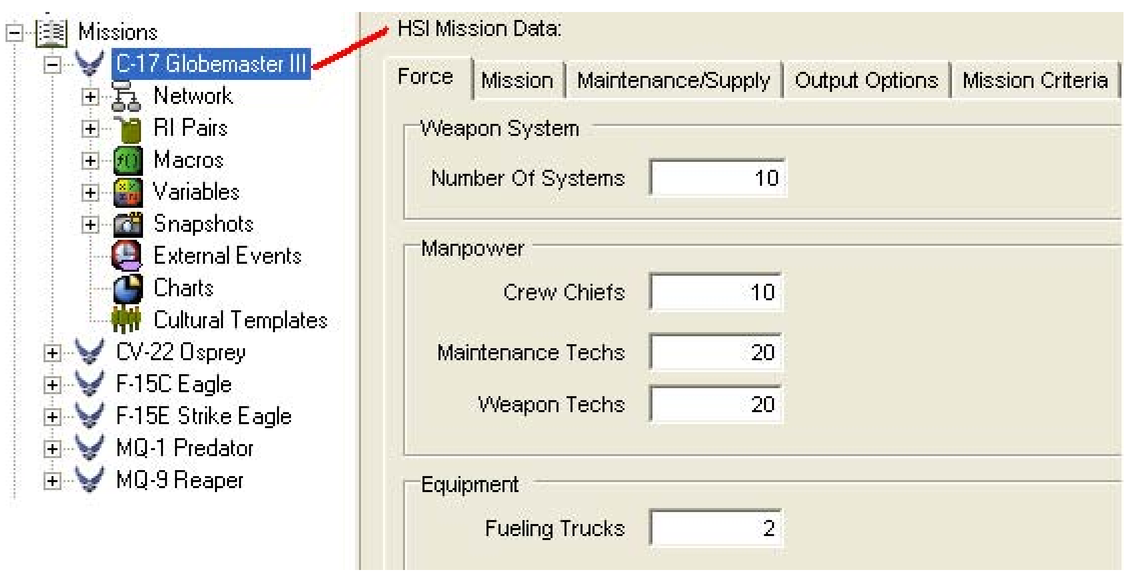


Figure 3-21. The AF HSI IMPRINT Mx Model GUI.

The GUI has been organized into four different categories accessed by selecting the corresponding tab at the top of the interface. The four categories are force, mission, maintenance/supply, and output options. (The mission criteria tab seen at the top right of Figure 3-21 is included in all missions of IMPRINT and allows the user to specify general criteria for a normal operations mission model.

Because the AF HSI Mx Model uses its own reports, there is no need for the user to enter information into the mission criteria tab). The remainder of this section explains each of the four categories in detail.

### 3.5.1 Force

The force tab (Figure 3-22) allows the analyst to modify information about the force structure, maintenance manning, and fuel equipment to describe the resources that will support the scenario.

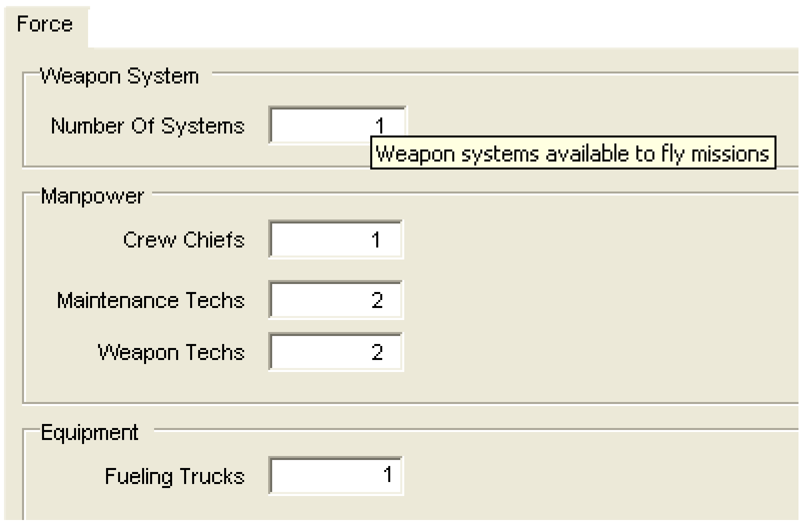


Figure 3-22. The Force Tab.

<u>Weapon System</u>

The number of weapon systems, also called the force structure, sets the initial amount of weapon systems that are available to fly missions in the scenario. If a weapon system is lost in battle – also known as an Attrite event – the number of available weapon systems will be reduced by one.

<u>Manpower</u>

In the manpower sub-category, the analyst can modify the available maintenance crew of crew chiefs, maintenance technicians and weapon technicians respectively.

<u>Equipment</u>

The fueling trucks field under the equipment sub-category lets the analyst set the number of trucks or tanks available to refuel the weapon systems during the scenario.

*Note on Tool Tips*

Each of the editable fields of the GUI provides the analyst with a tool tip – or descriptive text pop up – that further informs the analyst with a short description of the data for that field. Figure 3-22 shows an example of a tool tip where it reads: “Weapon systems available to fly missions.”

*Note on Default Values*

Each of the editable fields is pre-populated with default values that are the minimum required to be able to run a simulation. For example to support one C-17 Globemaster III weapon system, a minimum of one crew chief, two maintenance technicians, two weapon technicians, and one fueling truck is needed for the simulation to execute. Changing the editable field to a number lower than the minimum default value results in an error message (see Figure 3-23).

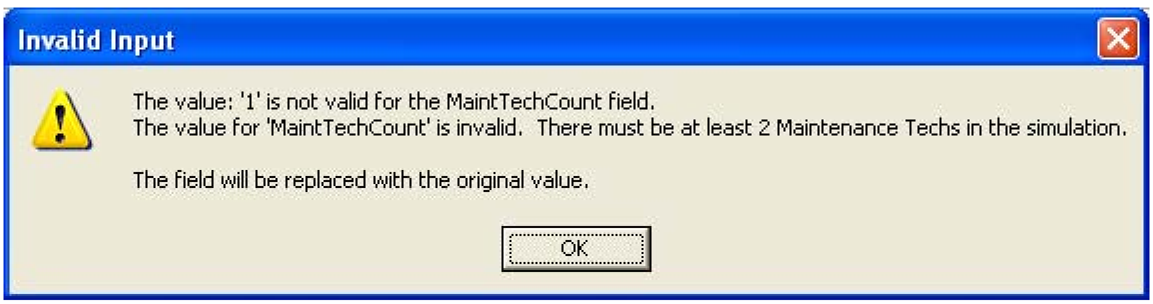


Figure 3-23. Error message for invalid number of maintenance technicians.

### 3.5.2 Mission

The mission tab (Figure 3-24) allows the analyst to describe the length of the simulation, operational tempo (OPSTEMPO), and the probability of any abort and Attrite events.

<u>Maintenance Scenario</u>

The simulation duration under the maintenance scenario sub-category lets the analyst set the end time for the simulation run. When the simulation clock has reached the time specified in the simulation duration, the simulation will finish writing data to the reports and then terminate the run. If more than one run is selected in the execution settings, the simulation will begin anew at time zero and then terminate again at the time specified by the user in the simulation duration field. IMPRINT will continue to simulate the scenario until all runs specified by the user have been executed.

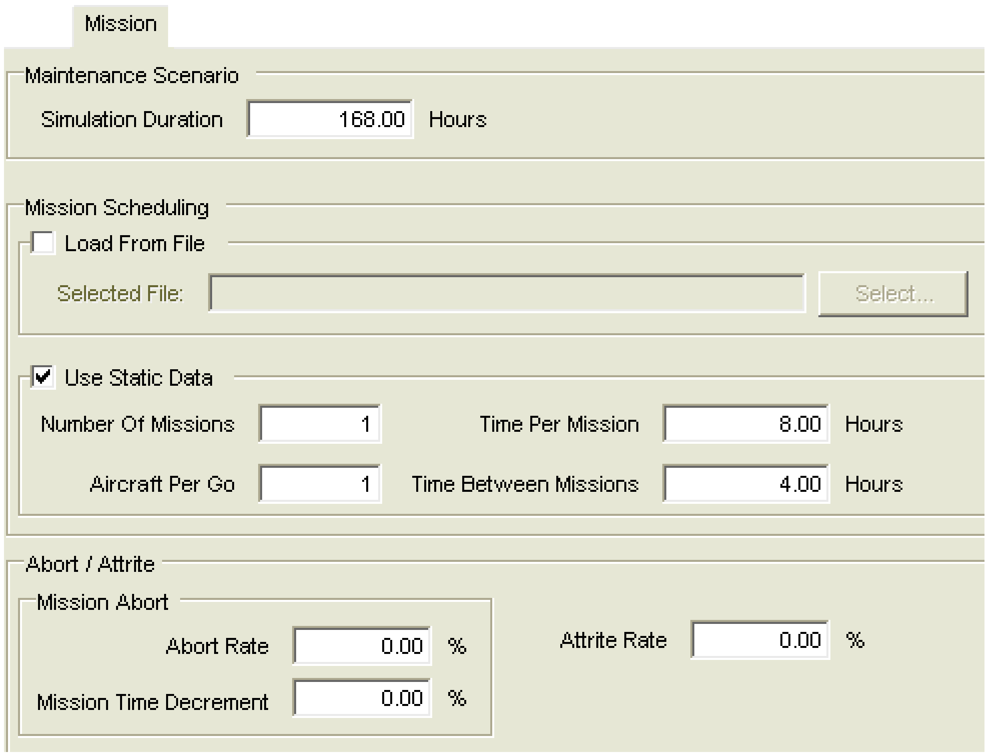


Figure 3-24. The Mission Tab.

Mission Scheduling

The mission scheduling feature provides the analyst with two methods to specify the scheduling of missions in the scenario: the "Load from File" option and the "Use Static Data" option. The check box lets the analyst pick which option to use to schedule the mission.

*Load from File* 


The "Load from File" scheduling option provides the analyst with the ability to control mission schedules based on mission generation start times and mission flying times. The user creates mission schedules using a Microsoft Excel worksheet (with an .xls extension) that is later read by IMPRINT before simulation execution.

Table 3-1, "Example Mission Scheduling Excel File," shows an example of how five missions scheduled over five successive days of a hypothetical scenario appear within the Microsoft Excel mission scheduling template file. The user must populate column A, "Takeoff Day," column B, "Mission Generation Start Hour (Military)," and column D, "Flight Time (Hours)" with data to describe when the aircraft starts the mission generation process and for how long the aircraft flies that particular mission. The template file will automatically populate Column C, 'start Hour from Day 1" with the appropriate start hour.

Table 3-10. Example Mission Scheduling Excel File.

| | A | B | C | D |
|---|---|---|---|---|
| 1 | Takeoff Day | Mission Generation Start Hour (Military) | Start Hour from Day 1 (do not modify column C) | Flight Time (Hours) |
| 2 | 1 | 00:25 | 0.42 | 3.2 |
| 3 | 2 | 03:18 | 27.30 | 5.1 |
| 4 | 3 | 07:12 | 55.20 | 4.3 |
| 5 | 4 | 10:48 | 82.80 | 2.8 |
| 6 | 5 | 10:48 | 106.80 | 2.8 |

*Note on Chronologically Ordering Missions in the Scheduling File*

It is important to note that the mission data must be entered in chronological order from the earliest mission to the last mission of the scenario. Failing to adhere to this instruction will result in an IMPRINT run time error.

*Use Static Data* 


The "Use Static Data" option is a simplified way of scheduling missions. This option requires four fields: 1) "Number of Missions", 2) "Time Per Mission", 3) "Aircraft Per Go," and 4) "Time Between Missions."

- Number of Missions: Specifies the number of missions intended to be flown in the scenario.

- Time Per Mission: Specifies the length of each mission.

- Aircraft Per Go: Specifies the number of weapon systems to start the mission generation process with identical start times. Often times, the Air Force will schedule several aircraft to fly missions at the same time. This field allows the user to set the number of aircraft that will fly the mission simultaneously. The number of aircrafts per go cannot be set to a number greater than the total number of systems available for that scenario. If an attempt is made to set it greater, the following message as shown in Figure 3-25 appears.


Figure 3-25. Error message for invalid input for number of aircrafts per go.

- Time Between Missions: If there is more than one mission to be flown, the analyst through this option can specify the time interval between the missions.

<u>Abort/Attrite</u>

Abort/Attrite allows for the analysis of abort or attrite rates on mission performance. “Abort Rate”, “Attrite Rate” and “Mission Time Decrement” are the three fields that the user can set to see the effect on a mission.

- Abort Rate: Percentage of missions that will have an air abort.

- Mission Time Decrement: Percentage that mission time will be reduced by when an abort occurs.

- Attrite Rate: Percentage of systems that will be lost due to attrition.

### 3.5.3 Maintenance/Supply

The maintenance/supply tab (Figure 3-24) allows the analyst to specify scenario details of maintainability and reliability of aircraft components for unscheduled maintenance, requirements of the contingency/combat inspection, Warfighter fatigue, and aircraft component supply statistics.

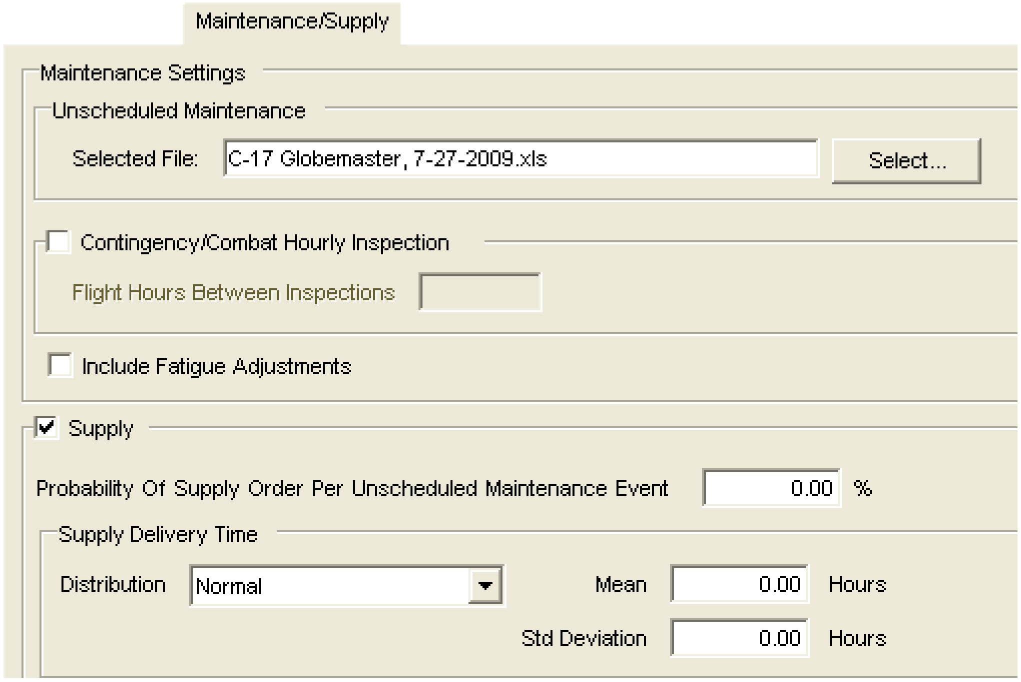


Figure 3-26. Maintenance/Supply tab.

<u>Maintenance Settings</u>

"Unscheduled Maintenance", "Contingency/Combat Hourly Inspection" and "Include Fatigue Adjustments" setting can be set under the maintenance settings.

- Unscheduled Maintenance Selected File: To accommodate the vast amount of maintenance data collected on reliability and maintainability, the team devised a way to quickly import data directly from Microsoft Excel in the *MAAD.Plugins.AirForceHSI.dll*.

    - Table 3-11, "Example Maintenance Excel Data Table," shows an example of how four work unit codes (WUCs) and their associated statistics appear within the Microsoft Excel file. The table includes columns for WUC, WUC description, mean reliability or maintainability statistic defined by the WUCs mean time between maintenance event (MTBME), mean event time (MET), MET standard deviation, mean event crew ratio (MECR), MECR standard deviation, and event count.

      Note: WUCs and associated statistics in this report have been adjusted to show notional examples.

➢ To generate the Microsoft Excel files containing the unscheduled maintenance data, the team extracted statistics from the Air Force Maintenance Data Collection System (MDCS). To make these datasets tailorable and updateable, the team developed the "AF HSI IMPRINT Pro Unscheduled Maintenance Metrics Tool." This tool contains both unit level and weapon system level statistics. The datasets for these statistics can be appended with new data beyond the date of the last queries as time moves forward. See section 7.8 for more information regarding the unscheduled maintenance metrics tool.

Table 3-11. Example maintenance excel data table.

| WUC | WUC Description | MTBME (hr) | MET (hr) | MET Std Dev (hr) | MECR | MECR Std Dev | Events |
|---|---|---|---|---|---|---|---|
| AT050 | AIRFRAME | 8,430 | 1.147 | 0.226 | 1.941 | 1.830 | 10 |
| 4BA04 | HATCHES, FUSELAGE | 936 | 0.684 | 0.649 | 1.65 | 0.546 | 190 |
| Z64F9 | NOC | 19,062 | 2.095 | 0.733 | 1.238 | 0.611 | 15 |
| M1A70 | DOOR INSTL | 511,307 | 2.000 | 0.000 | 7.000 | 0.000 | 1 |

Note: Failure to set the path to where the maintenance data is located on your computer network will result in an error message in the IMPRINT output window as shown in Figure 3-27.

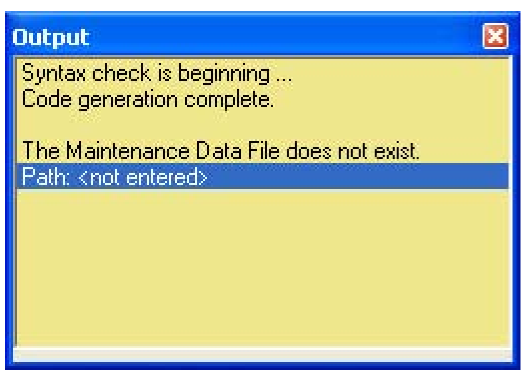


Figure 3-27. Error IMPRINT output message when the unscheduled maintenance file path has not been properly set.

- Contingency/Combat Hourly Inspection: If the system is subject to contingency/combat (C/C) inspections and if the corresponding field is checked in the interface, the analyst can enter the number of hours between (C/C) inspections.

- Include Fatigue Adjustments: By checking the "Include Fatigue Adjustments" check box, the analyst can see the effect of fatigue on task performance. The sleep activity fatigue task effectiveness (SAFTE) plug-in – a plug-in is a portable piece of software code saved with a .dll file extension that expands the capabilities of IMPRINT - model integrates quantitative information about (1) circadian rhythms in metabolic rate, (2) cognitive performance recovery rates associated with sleep, and cognitive performance decay rates associated with wakefulness, and (3) cognitive performance effects associated with sleep inertia to produce a 3-process model of human cognitive effectiveness. This measure of cognitive effectiveness thus affects the human's ability to perform a task by increasing or decreasing the time it takes for the human to perform a task. Once the SAFTE plug-in is loaded, the GUI as shown in Figure 3-28 is available to the user. For specific details on the capability of the SAFTE plug-in, please refer to the section on modeling fatigue found in the appendix in Section 7.6

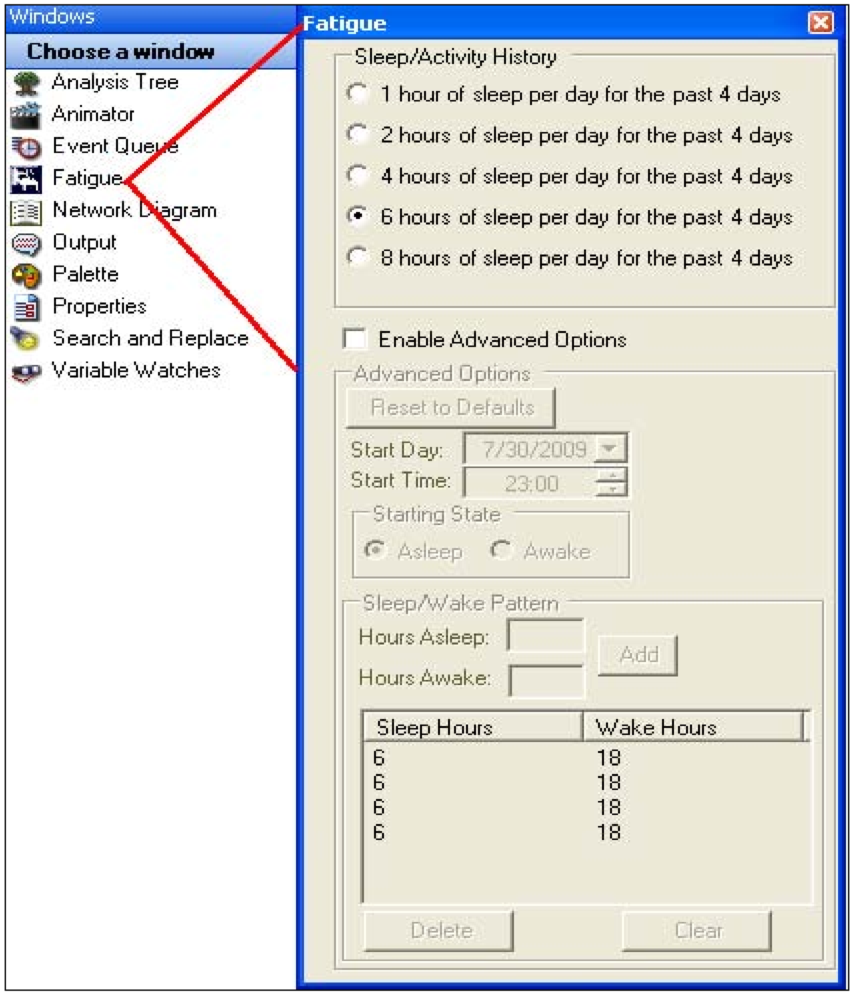


Figure 3-28. The IMPRINT Sleep Activity Fatigue Task Effectiveness Interface.

## Supply

To see the effects of supply parameters on mission performance and sortie generation rate, the analyst needs to select the corresponding check box of “Supply” as shown in Figure 3-29.

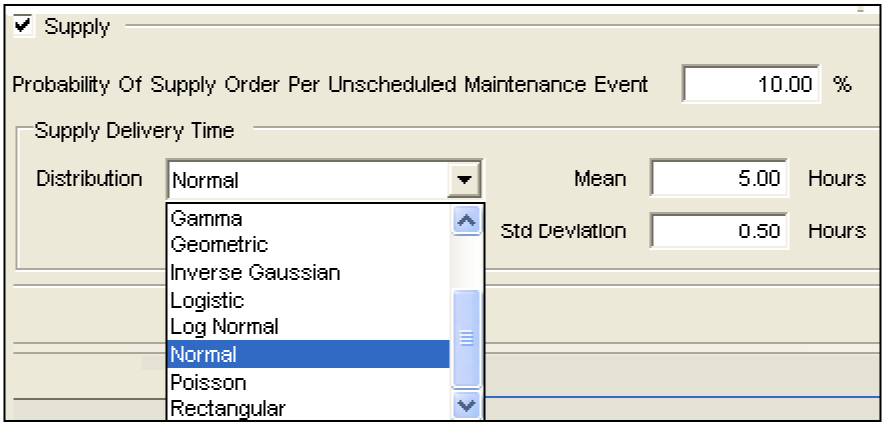


Figure 3-29. Supply parameters.

The “Probability Of Supply Order Per Unscheduled Maintenance Event” lets the analyst set the probability per unscheduled maintenance event that a supply part needs to be ordered. The analyst can also set the delivery time for the placed order by selecting from one of the twelve distribution types (e.g. normal, gamma, rectangular, etc.) and specifying the mean and standard deviation (if applicable to the selected distribution).

### 3.5.4 Output Options

All the output reports and charts can be accessed through the “Output Options” tab as shown in Figure 3-30.

Output Folder

The “Selected Folder” options lets the analyst set the path to the location of the folder where all the AF HSI analysis generated reports are written. Section 4.1 discusses in detail all the reports that are generated upon model run.

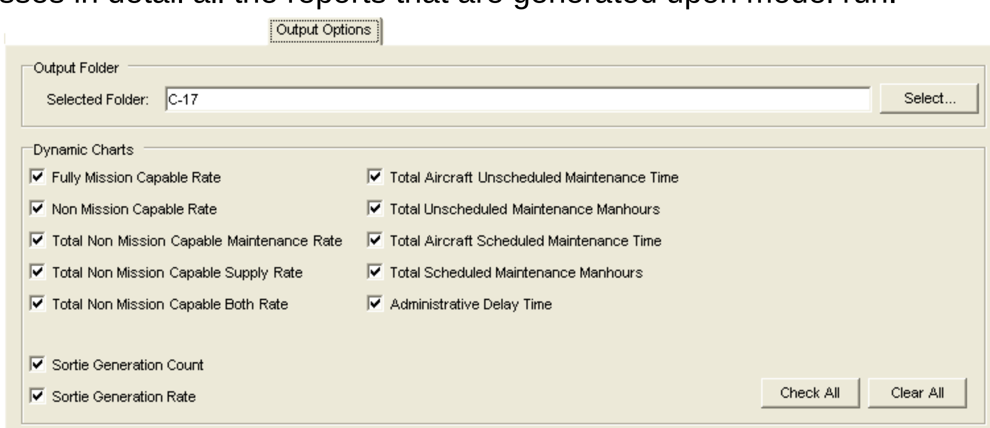


Figure 3-30. Output Options Tab.

Dynamic Charts

The dynamic chart sub-category allows the user to choose among 12 different operational metrics for dynamic plotting during simulation run-time. As the scenario unfolds, the values of the selected dependent variables are plotted showing up to the hour results. Below, Figure 3-31 illustrates the dynamic charting capability for all twelve operational metrics in a hypothetical scenario. Three charts are used to organize the data. The top chart holds the mission capability metrics. The center chart holds unscheduled, scheduled, and administrative delay man-hours and times. The bottom chart displays information on the sortie count and the daily sortie generation rate.

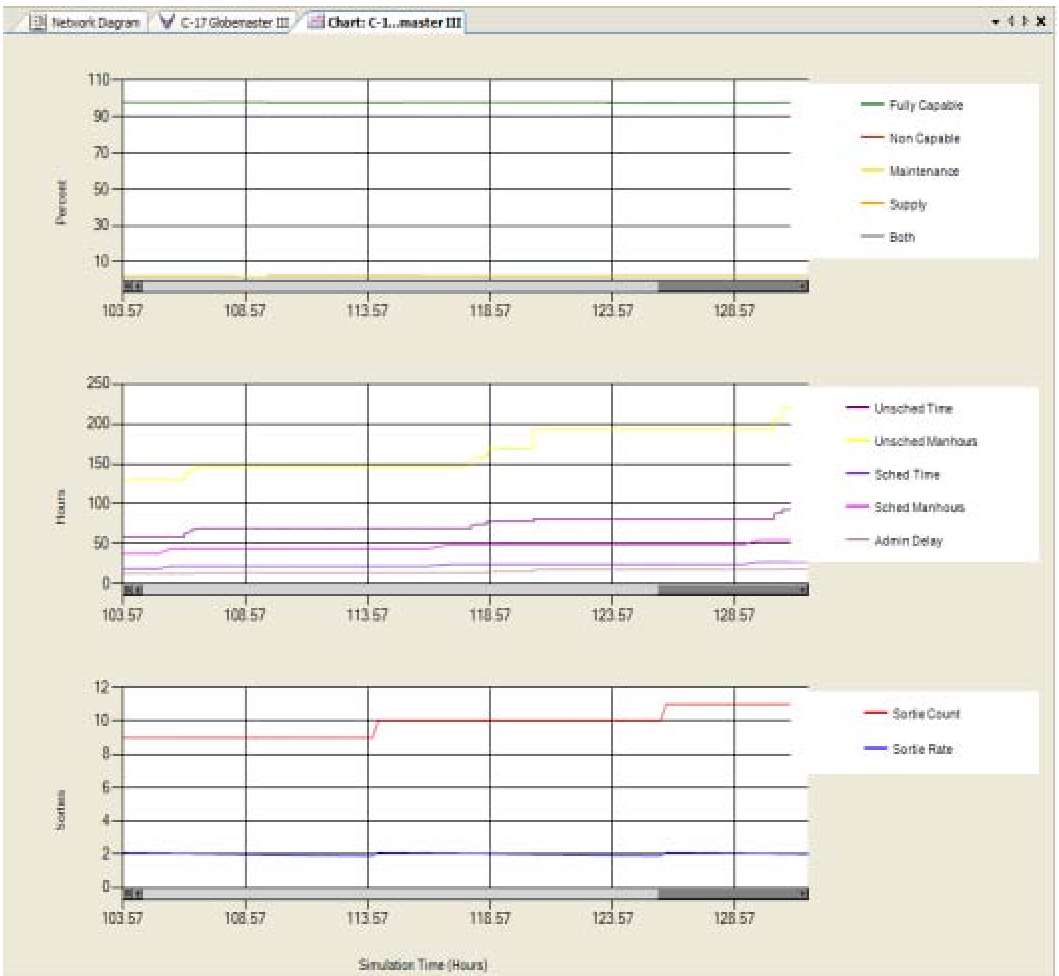


Figure 3-31. Dynamic Charts.

### 3.5.5 Execution Settings

The execution settings interface allows the analyst to set which mission to execute, the number of times to run the mission, and the random number seed. The analyst can introduce more variability in model execution by increasing the number of runs. To access the execution settings interface, select “Execution > Settings…” from the IMPRINT menu bar once an analysis has been opened. It is not recommended to alter the mission (or weapon system) at this location because the independent variables of the mission are not readily known. Instead, the execution settings interface should be used primarily for selecting the number of times to run the mission. To alter the mission (or weapon system), it is better to select the particular mission using the analysis tree and double-clicking on the preferred system under the mission area (Figure 3-20).

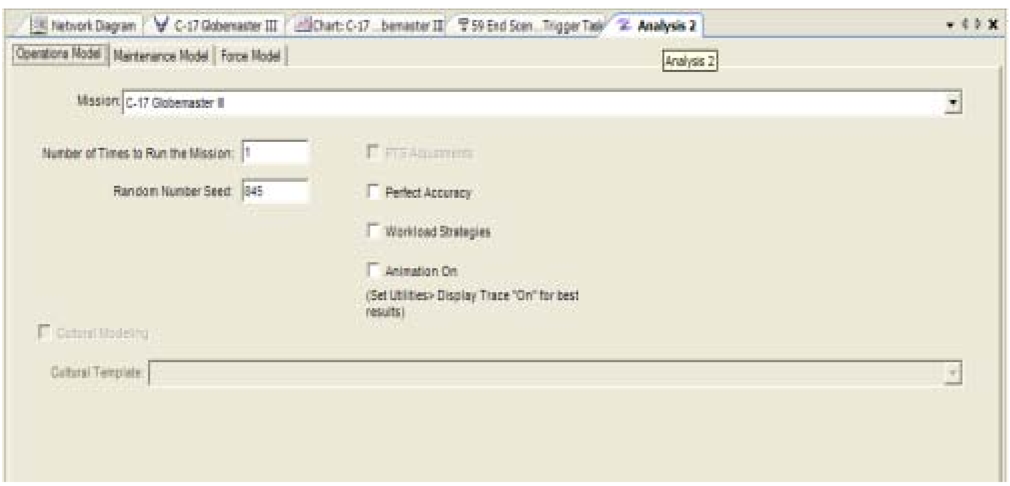


Figure 3-32. Execution Settings Interface.

## 3.6 Simplifying Assumptions

The developers of the AF HSI IMPRINT Pro Mx Model used several simplifying assumptions to narrow the scope of the simulation so that it could be developed within the constraints of the funded budget while still providing value to the AF. Firstly and foremost, the developers designed the simulation with a focus on the scheduled, routine, and unscheduled maintenance events of the flightline maintenance process. The team did not have time to consider major preventive scheduled maintenance (e.g. home station checks, hourly post flight inspections, and periodic inspections). To that end, the developers do not recommend using the tool to estimate and plan for mission scenarios longer than the intervals of these major scheduled maintenance inspections. In other words, the tool is currently geared towards planning for shorter mission scenarios. With additional support and funding towards model development, the impacts of major scheduled maintenance and other logistic processes could be incorporated into the IMPRINT Pro simulation.

The bullets below summarize the simplifying assumptions used in the development of the AF HSI IMPRINT Pro Mx Model:

- No programmed depot maintenance (PDM) and aerospace vehicle manufacturer maintenance
- No indirect/administrative work of crew chiefs, Mx technicians, or weapon technicians (only flightline manual labor was considered)
- Consideration of one weapon system at a time
- No weather, climate, or daylight/darkness
- No alert aircraft
- No functional check flights
- No cannibalization
- No integrated combat turns
- No backshop
- All aircraft start as fully mission capable
- Focuses on scheduled and unscheduled maintenance
    - Scheduled
        - Prior to launch walk around inspection
        - End of Runway (EOR)
        - Combined Pre-Flight/Basic Post-Flight (PR/BPO)
        - No hourly Post-flight (HPO), periodic (PE), pre-flight (PR), quick turn (QT), basic post-flight (BPO)
    - Unscheduled
        - Maintainability and reliability data retrieved from the Air Force Maintenance Data Collection System (MDCS)
- Supply times considered
- No hot refueling
- No support equipment maintenance considered
- No transient maintenance inspections
- No transfer or storage maintenance
- No decontamination required
- No aircraft battle damage repair (ABDR)
- No aircraft grounding
- Air aborts only
- No red ball maintenance but unscheduled maintenance actions are captured for red ball through the MDCS statistics

# 4 RESULTS AND DISCUSSION

## 4.1 Operational Metrics / Dependent Variables / Simulation Output

This section presents the results provided by the execution of the AF HSI IMPRINT Pro Mx Model. The results are stored in comma separated value (.csv) formatted files and one Microsoft Word (.doc) document found in the folder specified in the "Output Options Tab" as seen Section 3.5.4.

Model Settings Report

Figure 4-1 shows a notional example of the model settings report, revealing the independent variable settings chosen by the user before executing the simulation. This file will appear in the output directory as "Model Settings.doc."

```
FORCE

Number of Weapon Systems: 10
Number of Crew Chiefs: 10
Number of Mx Techs: 20
Number of Weapon Crews: 20
Number of Fuel Trucks: 3

MISSION

Number of Simulation Runs: 1
Simulation Duration (Hrs): 336
Actual Time Simulated (Hrs): 336
Number of Missions Scheduled: 84
Mission Time(Hrs): 10
Number of Aircraft Per Go: 2
Mission Interlaunch Time(Hrs): 8
Abort Rate: 7
 Mission Time Decrement: 0.97
Attrite Rate: 0.5

MAINTENANCE/SUPPLY

Unscheduled Mx Input File: C:\Program Files\IMPRINT Pro 3.0\AF_HSI\MDCS
Data\C-17\C-17 Globemaster, 7-15-2009.xls
Model Contingency/Combat Inspection: True
Model Contingency/Combat Inspection (Hrs): 35
Model Fatigue: False
Model Supply: True
Chance of Ordering Part from Supply (%): 1
Mean Supply Time (Hrs): 1
```

Figure 4-1. Example Model Settings Report.

Aircraft Flightline Maintenance Process Event Report

Table 4-1 shows a brief snapshot of the report written by IMPRINT Pro for all aircraft of the simulation. This report shows the execution run, day, hour, flightline maintenance event, manpower, and duration for each flightline maintenance event. Also shown is the total duration of the sortie generation cycle (a.k.a. the mission generation or flightline maintenance process) in the last column of the ‘sortie Generation Cycle Ends” row. In this case, the flightline maintenance process for this particular C-17 Globemaster III took 1,410 minutes (23.5 hours), including a 582 minute (9.7 hour) aborted mission. The aircraft event logs will appear in the output directory as “ACevents_n.csv,” where n is equal to 0 through the total number of weapon systems specified by the user before run time.

Table 4-1. Example Aircraft Flightline Maintenance Process Event Log.

| Run | Day | Hour | Event | Aircrew | Crew Chiefs | Mx Techs | Weapons | Duration(Mins) |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 0:00 | Mission Generation Cycle Begins | | | | | |
| 1 | 1 | 0:00 | Weapons crew attaches chaff and flare | 0 | 0 | 0 | 2 | 124 |
| 1 | 1 | 2:04 | Aerial port squadron loads cargo | 0 | 0 | 0 | 0 | 52 |
| 1 | 1 | 2:56 | Crew chief performs prior to launch walk around inspection of the C-17 | 0 | 1 | 0 | 0 | 52 |
| 1 | 1 | 3:48 | Aircrew and crew chief review the aircraft forms | 3 | 1 | 0 | 0 | 25 |
| 1 | 1 | 4:13 | Crew chief and Mx techs perform launch inspection | 0 | 1 | 2 | 0 | 53 |
| 1 | 1 | 5:06 | Crew chief and Mx crew marshals aircraft to taxiway | 0 | 1 | 2 | 0 | 9 |
| 1 | 1 | 5:15 | Aircrew taxies to the end of runway | 3 | 0 | 0 | 0 | 11 |
| 1 | 1 | 5:26 | Abort Mission | 3 | 0 | 0 | 0 | 582 |
| 1 | 1 | 15:08 | Aircrew touches down and lands aircraft | 3 | 0 | 0 | 0 | 1 |
| 1 | 1 | 15:09 | Aircrew taxies aircraft to parking spot | 3 | 0 | 0 | 0 | 10 |
| 1 | 1 | 15:19 | Crew chief and Mx techs perform recovery inspection of the C-17 | 0 | 1 | 2 | 0 | 50 |
| 1 | 1 | 16:09 | Crew chief and Mx tech perform basic post-flight/preflight inspection | 0 | 1 | 1 | 0 | 176 |
| 1 | 1 | 19:05 | Mx crew and Crew Chief fills tanks for next mission | 0 | 1 | 2 | 0 | 53 |
| 1 | 1 | 20:32 | Unscheduled Mx WUC XYZ01: TAILCONE | 0 | 0 | 2 | 0 | 13.4 |
| 1 | 1 | 20:32 | Unscheduled Mx WUC XYZ02: REFUELING | 0 | 0 | 1 | 0 | 16.9 |
| 1 | 1 | 20:35 | Unscheduled Mx WUC XYZ03: VARIABLE | 0 | 0 | 1 | 0 | 20.2 |
| 1 | 1 | 20:35 | Unscheduled Mx WUC XYZ04: SUBSYSTEM | 0 | 0 | 2 | 0 | 174.9 |
| 1 | 1 | 20:35 | Unscheduled Mx WUC XYZ05: DUCT | 0 | 0 | 2 | 0 | 52.7 |
| 1 | 1 | 20:45 | Unscheduled Mx WUC XYZ06: SENSOR | 0 | 0 | 3 | 0 | 50.7 |
| 1 | 1 | 20:55 | Unscheduled Mx WUC XYZ07: WHEEL | 0 | 0 | 2 | 0 | 91.6 |
| 1 | 1 | 21:07 | Unscheduled Mx WUC XYZ08: TIRE | 0 | 0 | 3 | 0 | 21.4 |
| 1 | 1 | 23:30 | Sortie Generation Cycle Ends | | | | | 1410 |

Aircraft Unscheduled Maintenance Event Report

Table 4-2 shows a brief snapshot of the report written by IMPRINT Pro for all aircraft that have had unscheduled maintenance performed during the simulation. This report shows when the unscheduled maintenance event takes place, the work unit code (WUC) and WUC description requiring maintenance, how many maintainers are necessary for the repair, the time to correct the failure, the accumulated unscheduled maintenance man-hours, accumulated unscheduled maintenance hours, accumulated flight time, and the mission start time and duration (sortie time) for the particular aircraft. The unscheduled maintenance event logs will appear in the output directory as "AC_CMevents_n.csv," where n is equal to 0 through the total number of weapon systems specified by the user before run time.

Table 4-2. Example Aircraft Unscheduled Maintenance Event Report.

| Run | Day | Hour | WUC | WUC Description | Event Time(Hrs) | Event Crew Ratio | Event Mx Manhours(Hrs) | Accrued AC Mx Manhours(Hrs) | Accrued AC Mx(Hours) | Accrued Flight Time(Hours) | Mission Time(Hrs) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 5:26 | | | | | | | | | 9.7 |
| 1 | 1 | 20:32 | XYZ01 | TAILCONE | 0.223 | 2 | 0.445 | 0.445 | 0.223 | 9.7 | |
| 1 | 1 | 20:32 | XYZ02 | REFUELING | 0.282 | 1 | 0.282 | 0.727 | 0.505 | 9.7 | |
| 1 | 1 | 20:35 | XYZ03 | RESTRAINT | 0.337 | 1 | 0.337 | 1.064 | 0.842 | 9.7 | |
| 1 | 1 | 20:35 | XYZ04 | SUBSYSTEM | 2.915 | 2 | 5.83 | 6.894 | 3.757 | 9.7 | |
| 1 | 1 | 20:35 | XYZ05 | DUCT | 0.879 | 2 | 1.758 | 8.652 | 4.636 | 9.7 | |
| 1 | 1 | 20:45 | XYZ06 | SENSOR | 0.844 | 3 | 2.533 | 11.185 | 5.48 | 9.7 | |
| 1 | 1 | 20:55 | XYZ07 | WHEEL | 1.526 | 2 | 3.053 | 14.238 | 7.006 | 9.7 | |
| 1 | 1 | 21:07 | XYZ08 | TIRE | 0.357 | 3 | 1.071 | 15.309 | 7.363 | 9.7 | |

## Abort Report

Table 4-3 shows an example of the report written by IMPRINT Pro for all aborted missions in the scenario. This report includes the simulation run, day and time of the event, the aircraft number, mission duration, and the total abort count. The abort report will appear in the output directory as “AbortEvents.csv,”

Table 4-3. Example Abort Report.

| Run | Day | Time | AC | Mission Time(Hours) | Abort Count |
|---|---|---|---|---|---|
| 1 | 1 | 5:26 | 0 | 9.7 | 1 |
| 1 | 2 | 22:33 | 1 | 9.7 | 2 |
| 1 | 4 | 5:25 | 9 | 9.7 | 3 |
| 1 | 4 | 5:44 | 8 | 9.7 | 4 |
| 1 | 5 | 5:15 | 4 | 9.7 | 5 |
| 1 | 6 | 6:00 | 1 | 9.7 | 6 |
| 1 | 8 | 13:34 | 4 | 9.7 | 7 |
| 1 | 8 | 21:44 | 9 | 9.7 | 8 |
| 1 | 9 | 21:13 | 7 | 9.7 | 9 |
| 1 | 13 | 21:35 | 3 | 9.7 | 10 |

## Attrite Report

Table 4-4 shows an example of the report written by IMPRINT Pro for all lost aircraft due to attrition in the scenario. This report includes the simulation run, day and time of the event, the aircraft number, mission duration, and the total attrite count. The attrite report will appear in the output directory as “AttriteEvents.csv.”

Table 4-4. Example Attrite Report.

| Run | Day | Time | AC | Mission Time(Hours) | Attrite Count |
|---|---|---|---|---|---|
| 1 | 6 | 21:34 | 5 | 10 | 1 |
| 1 | 11 | 13:35 | 7 | 10 | 2 |

## Administrative Delay Time Report

Table 4-5 shows a brief snapshot of the report written by IMPRINT Pro that captures how long an aircraft must wait until maintenance specialists are available to perform an unscheduled maintenance event. This report captures when the repair begins, the aircraft number needing the repair, the WUC needing the repair, and how long the aircraft waited for available maintenance personnel. The administrative delay time report will appear in the output directory as “CMadministrativeDelayTimes.csv.”

Table 4-5. Example Administrative Delay Time Report.

| Run | Day | Hour | AC# | WUC | WUC Description | Delay (Hrs) |
|---|---|---|---|---|---|---|
| 1 | 1 | 19:50 | 1 | YZX01 | TIRE | 0 |
| 1 | 1 | 19:50 | 1 | YZX02 | LIGHT | 0 |
| 1 | 1 | 19:50 | 1 | YZX03 | CONTROL | 0 |
| 1 | 1 | 19:50 | 1 | YZX04 | VALVE | 0 |
| 1 | 1 | 19:50 | 1 | YZX05 | BATTERY | 0 |
| 1 | 1 | 19:50 | 1 | YZX06 | WHEEL | 0 |
| 1 | 1 | 19:59 | 1 | YZX07 | SPINDLE | 0.15 |
| 1 | 1 | 20:11 | 1 | YZX08 | FUSELAGE | 0.361 |
| 1 | 1 | 20:32 | 0 | YZX09 | TAILCONE | 0.56 |
| 1 | 1 | 20:32 | 0 | YZX10 | REFUELING | 0.56 |

## Unscheduled Maintenance Event Report

Table 4-6 shows a brief snapshot of the report written by IMPRINT Pro that captures all the unscheduled maintenance events that occur in the simulated scenario. This report captures when the run number, day and hour of the repair, the aircraft number that is being repaired, the WUC and WUC description, the event time, event crew ratio, and the total event man-hours. The unscheduled maintenance event report will appear in the output directory as “CMevents.csv.”

Table 4-6. Example Unscheduled Maintenance Event Report.

| Run | Day | Hour | AC# | WUC | WUC Description | Event Time(Hrs) | Event Crew Ratio | Event Mx Manhours(Hrs) |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 19:50 | 1 | ZYT10 | TIRE | 1.285 | 3 | 3.856 |
| 1 | 1 | 19:50 | 1 | ZYT11 | LIGHT | 3.544 | 2 | 7.087 |
| 1 | 1 | 19:50 | 1 | ZYT12 | CONTROL | 0.758 | 3 | 2.273 |
| 1 | 1 | 19:50 | 1 | ZYT13 | VALVE | 3.755 | 3 | 11.264 |
| 1 | 1 | 19:50 | 1 | ZYT14 | BATTERY | 2.177 | 3 | 6.531 |

Unscheduled Maintenance Cycle Report

Table 4-7 shows a snapshot of the report written by IMPRINT Pro that captures the duration of the unscheduled maintenance performed by maintainers per flightline maintenance process cycle. That is, after an aircraft has flown a mission what is the length of time it receives unscheduled maintenance. This report captures the run, day and hour, aircraft number, the unscheduled maintenance cycle duration, the maximum supply delivery time for that cycle, the maximum unscheduled event time for that cycle, the total non mission capable maintenance time, the total non mission capable supply time, the total non mission capable both time, the non mission capable maintenance time for that aircraft, the non mission capable supply time for that aircraft, and the non mission capable both time for that aircraft. The unscheduled maintenance cycle report will appear in the output directory as “CMeventsCycle.csv.”

Table 4-7. Example Unscheduled Maintenance Cycle Report.

| Run | Day | Hour | AC# | CM cycle duration(Hrs) | Max cycle supply time(Hrs) | Max cycle event time(Hrs) | Total NMCM time(Hrs) | Total NMCS time(Hrs) | Total NMCB time(Hrs) | AC NMCM time(Hrs) | AC NMCS time (Hrs) | AC NMCB time(Hrs) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 23:30 | 0 | 3.52 | 0 | 2.915 | 3.52 | 0 | 0 | 3.52 | 0 | 0 |
| 1 | 1 | 23:35 | 1 | 3.755 | 0 | 3.755 | 7.275 | 0 | 0 | 3.755 | 0 | 0 |
| 1 | 2 | 7:30 | 2 | 3.168 | 0 | 3.168 | 10.443 | 0 | 0 | 3.168 | 0 | 0 |
| 1 | 2 | 8:05 | 3 | 3.543 | 0 | 3.543 | 13.986 | 0 | 0 | 3.543 | 0 | 0 |
| 1 | 2 | 13:57 | 5 | 0.905 | 0 | 0.905 | 14.891 | 0 | 0 | 0.905 | 0 | 0 |

## Environment, Safety, and Occupational Health Report

Table 4-8 shows the report written by IMPRINT Pro that captures the ESOH touch points accrued by maintenance specialist throughout the course of the scenario. Using this report, an AF analyst can perform trade-offs and assess the risk of different flightline maintenance process designs. By manipulating the design of the flightline maintenance process to represent different system acquisition design alternatives, the AF analyst can discover the true ESOH impact to the maintenance specialist. This report captures the number of environment touch points – when a maintenance specialist uses an environmentally hazardous chemical (e.g., JP-5 diesel), the number of primary and secondary safety hazards – when a maintenance specialist is directly or indirectly exposed to a safety hazard (e.g., tripping over cables connected to the aircraft), and the number of primary and secondary occupational health hazards – when a maintenance specialist is directly or indirectly exposed to an occupational health hazard (e.g., long term exposure to loud engine noise). The environment, safety, and occupational health report will appear in the output directory as “ESOH.csv.”

Table 4-8. Example Environment, Safety, And Occupational Health Report.

| Run | Environment | Safety Primary | Safety Secondary | Occ Health Primary | Occ Health Secondary |
|---|---|---|---|---|---|
| 1 | 1553 | 2205 | 164 | 2037 | 332 |

## Flying Schedule Effectiveness Report

Table 4-9 shows the report written by IMPRINT Pro that captures the flying schedule effectiveness of the simulated scenario. This report allows the AF analyst to compare, for each scheduled mission, the time when an aircraft was scheduled to begin the flightline maintenance process against the actually beginning time. Ideally, the last column will show no difference meaning that there was an adequate amount of manpower and time between each mission to meet the flying schedule. The flying schedule effectiveness report will appear in the output directory as “FSEexcel.csv.”

Table 4-9. Example Flying Schedule Effectiveness Report.

| Run | Mission # | AC# | Scheduled Day | Scheduled Time | Actual Day | Actual Time | Difference(Hrs) |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 0 | 1 | 0:00 | 1 | 0:00 | 0 |
| 1 | 2 | 1 | 1 | 0:00 | 1 | 0:00 | 0 |
| 1 | 3 | 2 | 1 | 8:00 | 1 | 8:00 | 0 |
| 1 | 4 | 3 | 1 | 8:00 | 1 | 8:00 | 0 |
| 1 | 5 | 4 | 1 | 16:00 | 1 | 16:00 | 0 |
| 1 | 6 | 5 | 1 | 16:00 | 1 | 16:00 | 0 |

Maintenance Manhour Report

Table 4-9 shows the report written by IMPRINT Pro that captures the maintenance man-hour report. This report allows the AF analyst to review the man-hours required to support the scenario by crew chief, maintenance specialist, and weapon specialist. The report divides man-hours into three categories: scheduled maintenance, unscheduled maintenance, and routine maintenance. Scheduled maintenance is maintenance that is specifically called out in the official “-6” work card deck. Unscheduled maintenance is maintenance performed when a work unit code (WUC) component requires correction after flying a mission. Routine maintenance is maintenance that is not called out in the official “-6” work card deck but nonetheless is required of the maintenance team for the successful generation of missions. The maintenance man-hour report will appear in the output directory as “ManhourReport.csv.”

Table 4-10. Example Maintenance Man-Hour Report.

| Run | CC MHs | CC Sched Insp MHs | CC Rout MHs | Mx Tech MHs | Mx Tech Sched MHs | Mx Tech Rout MHs | Mx Tech Unsched MHs | Weap MHs | Weap Sched Insp MHs | Weap Rout MHs |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 526.458 | 213.229 | 313.229 | 2268.299 | 0 | 412.421 | 1855.878 | 335.239 | 0 | 335.239 |

Operational Metrics Report

Table 4-11 and Table 4-12 show the report written by IMPRINT Pro that captures the operational metrics for the simulated scenario. Because of its length, this Final Report document shows the report through two tables. Included in this report, is the simulation run number, scenario duration, total aircraft unscheduled maintenance time, total unscheduled maintenance man-hours, total aircraft scheduled maintenance time, total aircraft scheduled maintenance man-hours, total administrative delay time, fully mission capable rate, total non mission capable maintenance rate, total non mission capable supply rate, total non mission capable both rate, sortie count, daily sortie generation rate, daily sortie generation rate per aircraft, abort count, and attrite count. The operational metrics report will appear in the output directory as “Operational Metrics.csv.”

Table 4-11. Example Operational Metrics Report (1st Half).

| Run | Model Duration (Days) | Total AC Unscheduled Mx Time (Hrs) | Total Unscheduled Mx Manhours(Hrs) | Total AC Scheduled Mx Time (Hrs) | Total AC Scheduled Mx Manhours(Hrs) |
|---|---|---|---|---|---|
| 1 | 14 | 727.936 | 1855.878 | 213.229 | 426.459 |

Table 4-12. Example Operational Metrics Report (2nd Half).

| Admin Delay Time(Hrs) | FMC | TNMCM | TNMCS | TNMCB | Sortie Count | Sortie Gen Rate (per day) | Sortie Gen Rate (per day per AC) | Abort Count | Attrite Count |
|---|---|---|---|---|---|---|---|---|---|
| 132.599 | 0.913 | 0.085 | 0.001 | 0.002 | 72 | 5.143 | 0.514 | 10 | 2 |

## Flightline Maintenance Process Times Report

Table 4-13 shows an example of the report written that captures the flightline maintenance process times report. This report shows the total maintenance time, not including the mission time, for each flightline maintenance and mission generation cycle. The AF analyst can use this report as a method for estimating the average time it takes an aircraft to process through the flightline maintenance and mission generation process that includes unscheduled maintenance. In the example table below, the cycle time fluctuates between 12 and 19 hours. The flightline maintenance process times report will appear in the output directory as 'sortie Gen Cycle Mx Times.csv."

Table 4-13. Example Flightline Maintenance Process Times Report.

This report shows the total Mx time (excluding mission time) for all sortie generation cycles.

| Run | AC | Cycle Time(Hrs) |
|---|---|---|
| 1 | 0 | 13.49556422 |
| 1 | 1 | 13.58008344 |
| 1 | 2 | 13.50521407 |
| 1 | 3 | 14.08104505 |
| 1 | 5 | 11.95604456 |
| 1 | 4 | 12.98082095 |
| 1 | 6 | 13.20278188 |
| 1 | 7 | 13.82455827 |
| 1 | 9 | 10.64383351 |
| 1 | 8 | 19.23368406 |

## Sortie Events Report

Table 4-14 shows an example of the report written by IMPRINT Pro that captures all the sorties of the simulated scenario. This report shows the run, day and time, aircraft number, mission time, and sortie count. The sortie events report will appear in the output directory as ‘sortieEvents.csv.”

Table 4-14. Example Sortie Events Report.

| Run | Day | Time | AC | Mission Time(Hours) | Sortie Count |
|---|---|---|---|---|---|
| 1 | 1 | 5:23 | 1 | 10 | 1 |
| 1 | 1 | 13:46 | 2 | 10 | 2 |
| 1 | 1 | 13:49 | 3 | 10 | 3 |
| 1 | 1 | 22:30 | 5 | 10 | 4 |
| 1 | 1 | 22:36 | 4 | 10 | 5 |
| 1 | 2 | 5:30 | 7 | 10 | 6 |
| 1 | 2 | 5:35 | 6 | 10 | 7 |
| 1 | 2 | 13:09 | 9 | 10 | 8 |
| 1 | 2 | 13:16 | 8 | 10 | 9 |
| 1 | 2 | 22:13 | 0 | 10 | 10 |

Supply Events Report

Table 4-15 shows an example report written by IMPRINT Pro that captures all the supply events of the simulated scenario. This report shows the simulation run, day and hour, aircraft number, ordered work unit code (WUC) component, a description of the WUC, and the delivery time. The supply events report will appear in the output directory as ‘supplyEvents.csv.”

Table 4-15. Example Supply Events Report.

| Run | Day | Hour | AC# | WUC | WUC Description | Delivery Time(Hrs) |
|---|---|---|---|---|---|---|
| 1 | 4 | 19:38 | 8 | MNN06 | TRANSMITTER | 0.1 |
| 1 | 6 | 20:24 | 1 | MNM07 | BAG | 4.5 |
| 1 | 12 | 3:59 | 6 | MNN07 | AXLE | 2.4 |
| 1 | 13 | 19:58 | 1 | MNM08 | LIGHTING | 0 |

Unscheduled Maintenance Events Tally Report

Table 4-16 shows an example report written by IMPRINT Pro that captures a tally of all the unscheduled maintenance events of the scenario. The report shows the simulation run, the broken Work Unit Code (WUC), the WUC description, number of times this WUC component failed in the scenario, the average time to repair the component, the average crew ratio size, and the average man-hours needed to repair the component. The AF analyst can use this report to understand which WUCs were seen the most frequently by the maintenance team in the scenario. The unscheduled maintenance events tally report will appear in the output directory as “Unscheduled Mx Event Tally.csv.”

Table 4-16. Unscheduled Maintenance Event Report.

| Run | WUC | WUC Description | Num of Events | Avg Time of Event(Hrs) | Avg Crew Ratio | Avg Manhours Per Event(Hrs) |
|---|---|---|---|---|---|---|
| 1 | 12XCC | DOOR | 1 | 4.24 | 2 | 8.48 |
| 1 | 51BA0 | INDICATOR | 1 | 0.24 | 2 | 0.48 |
| 1 | 57MB0 | COMPUTER | 3 | 2.14 | 2.33 | 4.9862 |
| 1 | 72EE0 | ANTENNA | 1 | 0.44 | 2 | 0.88 |
| 1 | 24SB0 | IGNITOR | 1 | 0.56 | 2 | 1.12 |

Administrative Delay Time Chart

Figure 4-2 shows the chart created in Microsoft Excel from the “Chart_AdministrativeDelayTime.csv” file written by IMPRINT Pro. This chart captures the evolution of the administrative delay time over the course of the simulation. An example 14 day scenario has been charted.

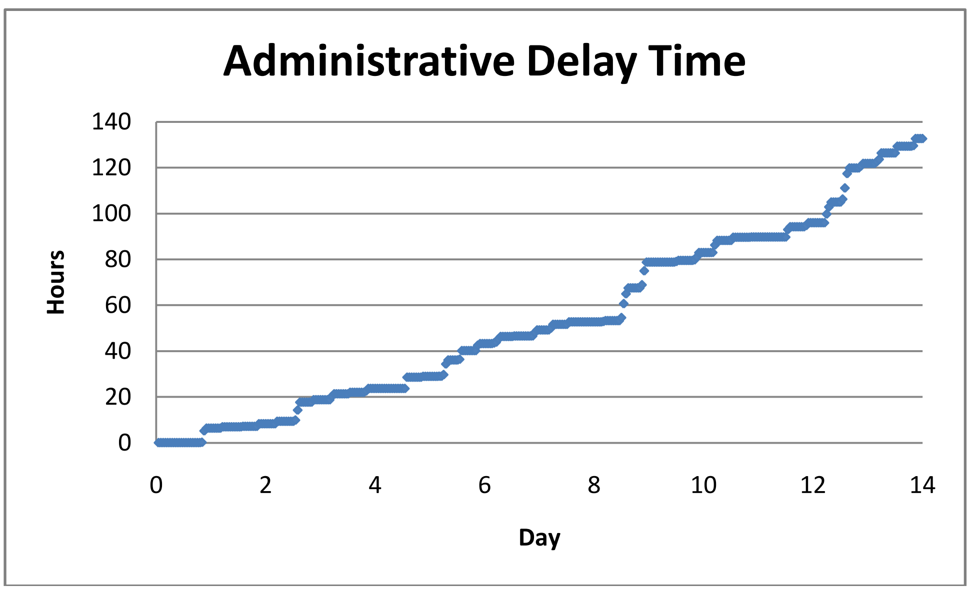


Figure 4-2. Example Administrative Delay Time Chart.

Fully Mission Capable Chart

Figure 4-3 shows the chart created in Microsoft Excel from the “Chart_FullyMissionCapableRate.csv” file written by IMPRINT Pro. This chart captures the evolution of the FMC rate value over the course of the simulation. An example 14 day scenario has been charted.

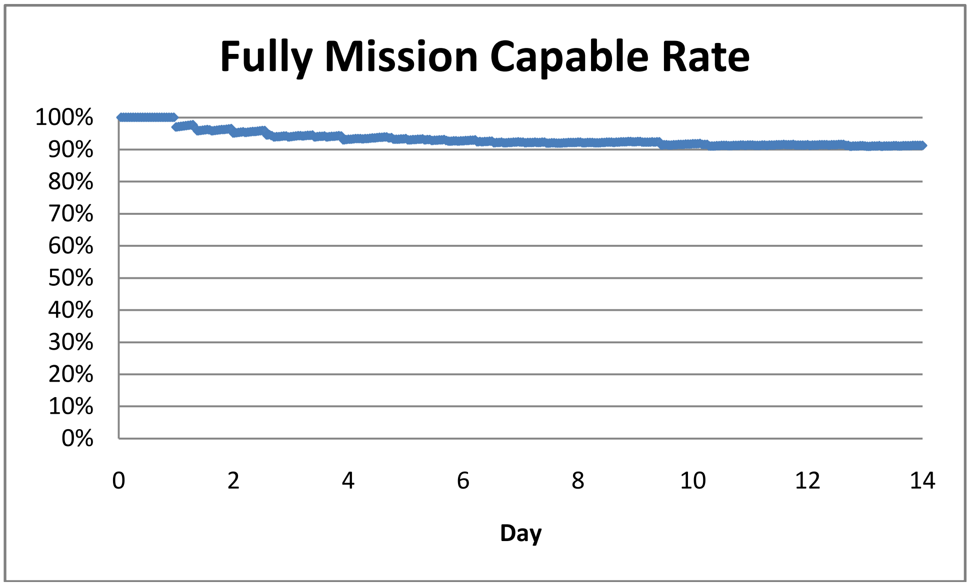


Figure 4-3. Example Fully Mission Capable Rate Chart.

Non Mission Capable Chart

Figure 4-4 shows the chart created in Microsoft Excel from the "Chart_NonMissionCapableRate.csv" file written by IMPRINT Pro. This chart captures the evolution of the NMC rate value over the course of the simulation. An example 14 day scenario has been charted.

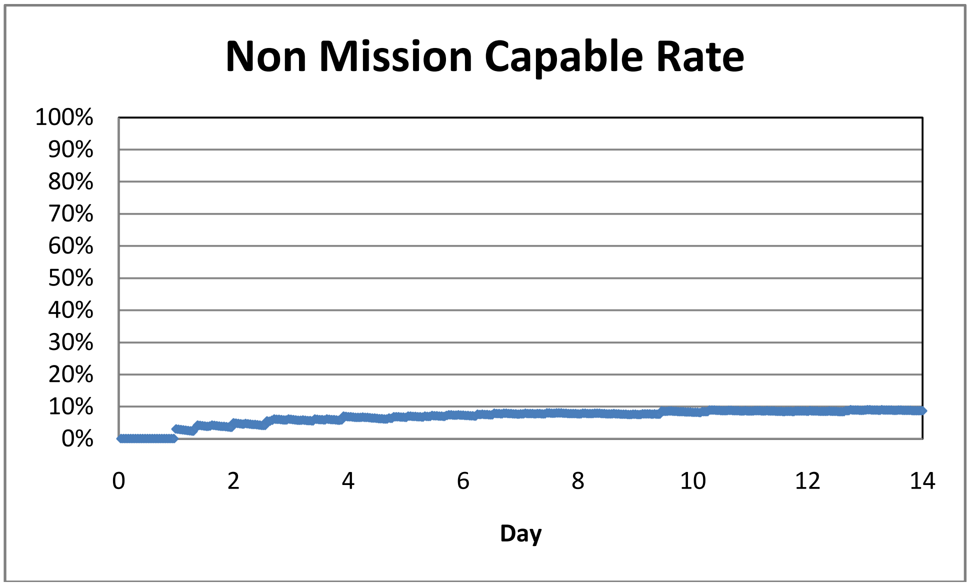


Figure 4-4. Example Non Mission Capable Rate Chart.

Sortie Count Chart

Figure 4-5 shows the chart created in Microsoft Excel from the "Chart_SortieGenerationCount.csv" file written by IMPRINT Pro. This chart captures the evolution of completed sorties over the course of the simulation. An example 14 day scenario has been charted.

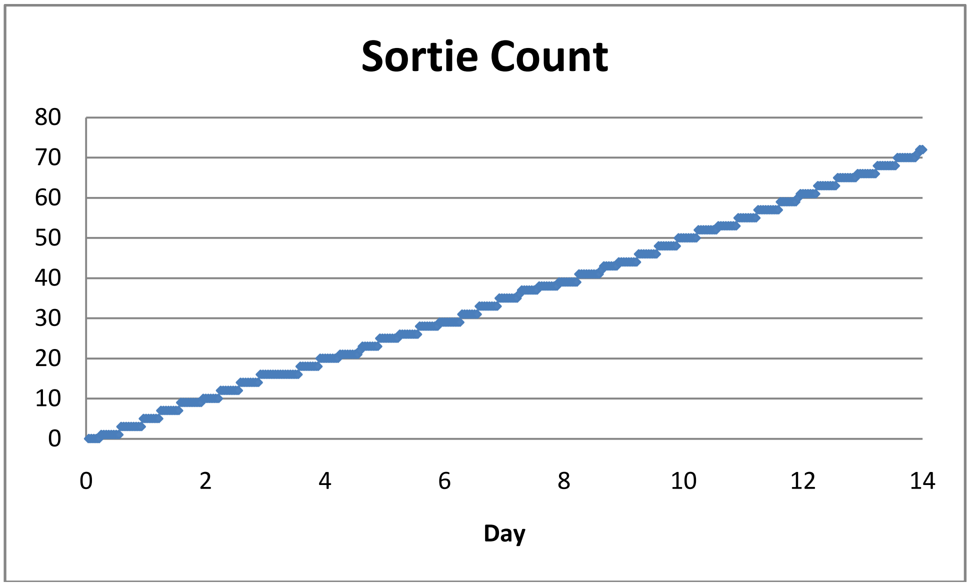


Figure 4-5. Example Sortie Count Chart.

Sortie Generation Rate Per Day Chart

Figure 4-6 shows the chart created in Microsoft Excel from the "Chart_SortieGenerationRatePerDay.csv" file written by IMPRINT Pro. This chart captures the evolution of the sortie generation rate per day over the course of the simulation. An example 14 day scenario has been charted.

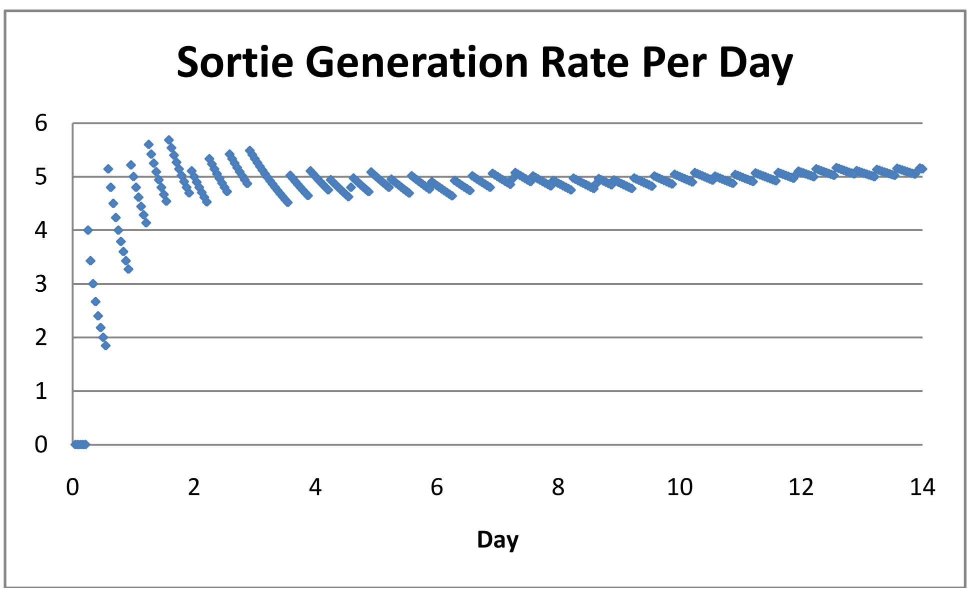


Figure 4-6. Example Sortie Generation Rate Per Day Chart.

Total Scheduled Maintenance Man-hours Chart

Figure 4-7 shows the chart created in Microsoft Excel from the "Chart_TotalAircraftScheduledMaintenanceManhours.csv" file written by IMPRINT Pro. This chart captures the evolution of the maintenance man-hours over the course of the simulation. An example 14 day scenario has been charted.

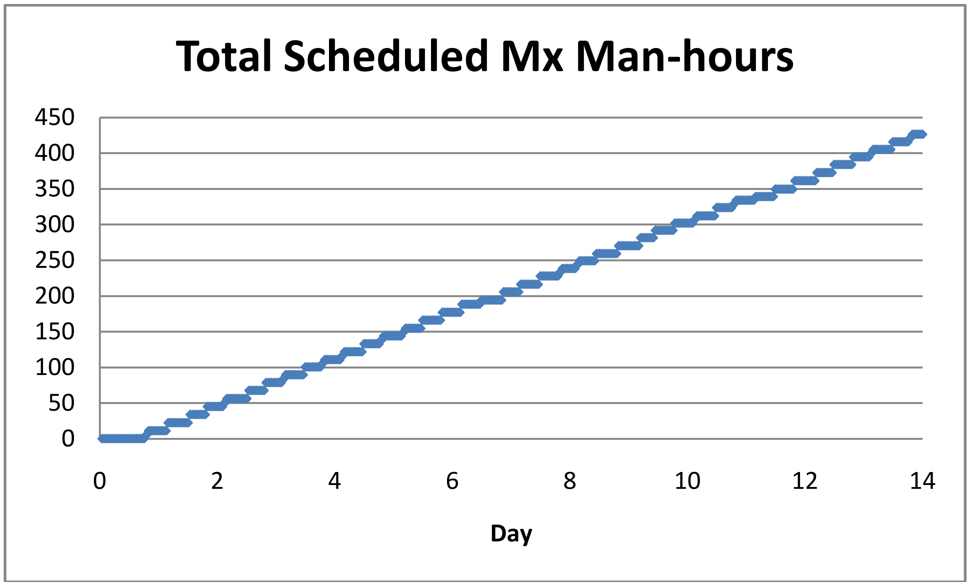


Figure 4-7. Example Total Scheduled Maintenance Man-Hours Chart.

Total Aircraft Scheduled Maintenance Time Chart

Figure 4-8 shows the chart created in Microsoft Excel from the "Chart_TotalAircraftScheduledMaintenanceTime.csv" file written by IMPRINT Pro. This chart captures the evolution of the total aircraft scheduled maintenance time over the course of the simulation. An example 14 day scenario has been charted.

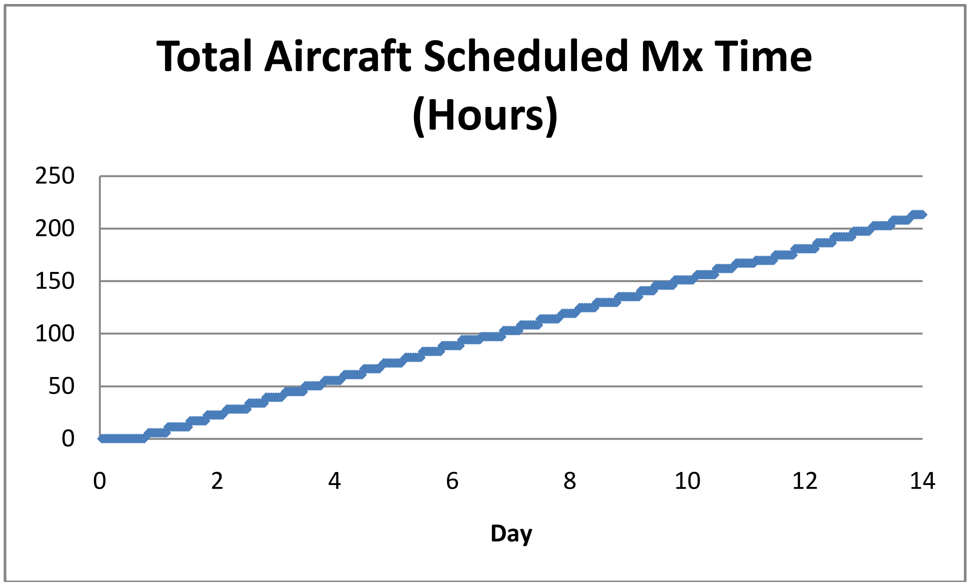


Figure 4-8. Example Total Aircraft Scheduled Maintenance Time Chart.

Total Aircraft Unscheduled Maintenance Time Chart

Figure 4-9 shows the chart created in Microsoft Excel from the "Chart_TotalAircraftUnscheduledMaintenanceTime.csv" file written by IMPRINT Pro. This chart captures the evolution of the total aircraft unscheduled maintenance time over the course of the simulation. An example 14 day scenario has been charted.

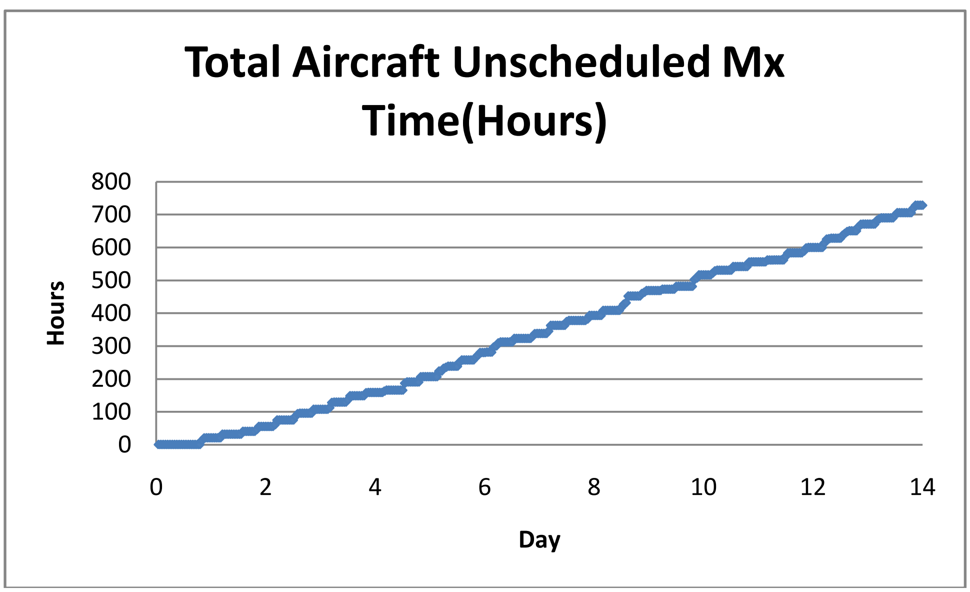


Figure 4-9. Example Total Aircraft Unscheduled Maintenance Time Chart.

Total Non Mission Capable Both Rate

Figure 4-10 shows the chart created in Microsoft Excel from the "Chart_TotalNonMissionCapableBothRate.csv" file written by IMPRINT Pro. This chart captures the evolution of the non mission capable both rate over the course of the simulation. An example 14 day scenario has been charted.

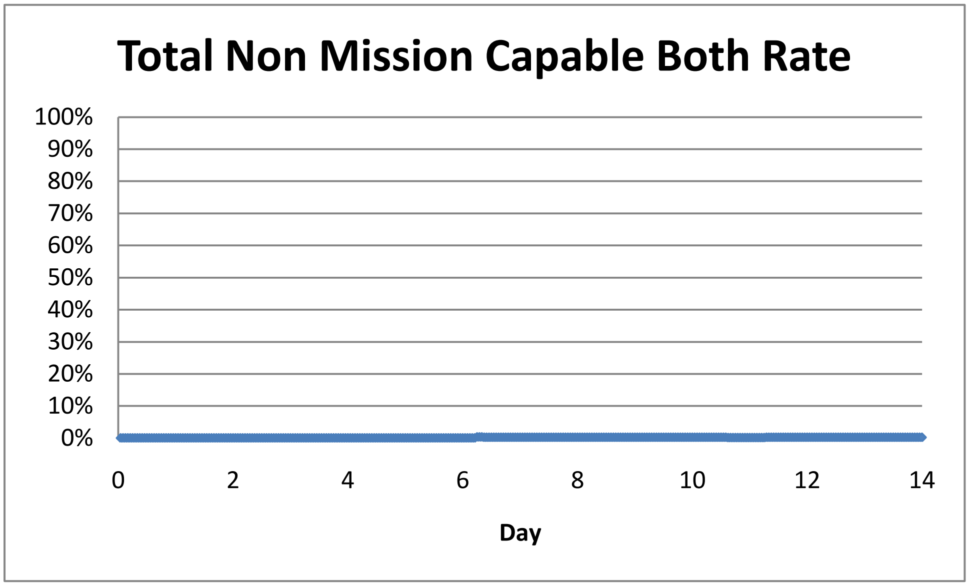


Figure 4-10. Example Total Non Mission Capable Both Rate Chart.

Total Non Mission Capable Maintenance Rate Chart

Figure 4-10 shows the chart created in Microsoft Excel from the "Chart_TotalNonMissionCapableMaintenanceRate.csv" file written by IMPRINT Pro. This chart captures the evolution of the non mission capable maintenance rate over the course of the simulation. An example 14 day scenario has been charted.

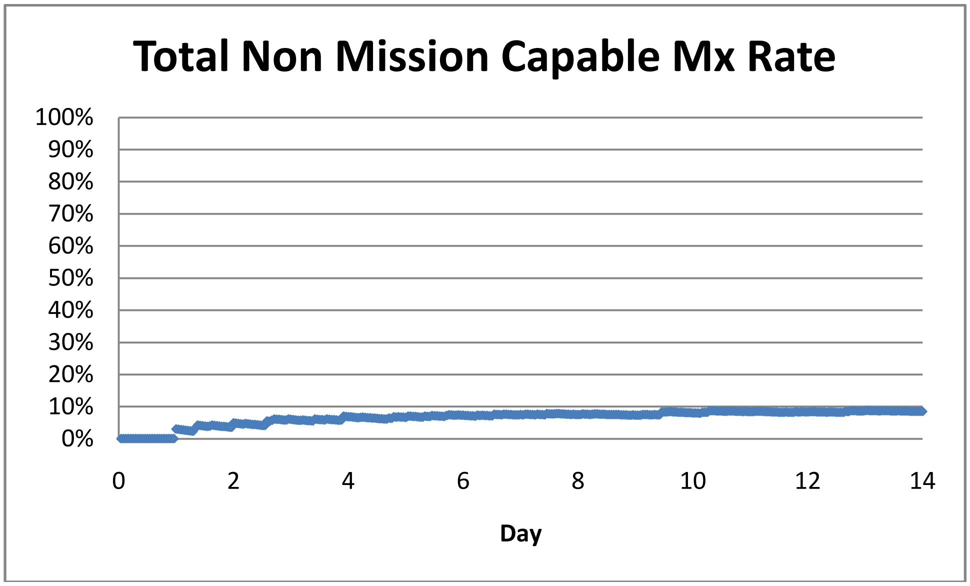


Figure 4-11. Example Total Non Mission Capable Maintenance Rate Chart.

Total Non Mission Capable Supply Rate Chart

Figure 4-12 shows the chart created in Microsoft Excel from the "Chart_TotalNonMissionCapableSupplyRate.csv" file written by IMPRINT Pro. This chart captures the evolution of the non mission capable supply rate over the course of the simulation. An example 14 day scenario has been charted.

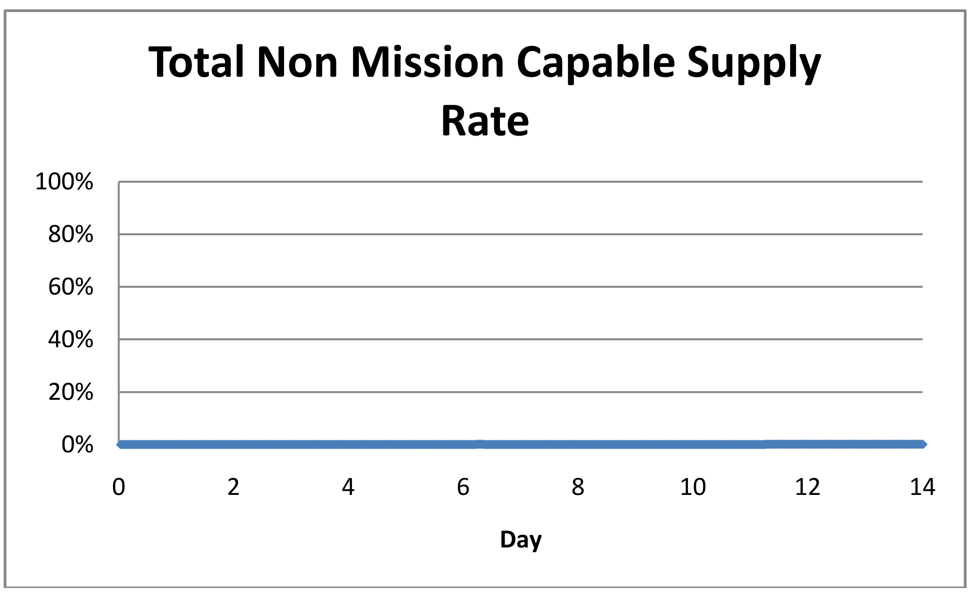


Figure 4-12. Example Total Non Mission Capable Supply Rate Chart.

Total Unscheduled Maintenance Man-hours Chart

Figure 4-13 shows the chart created in Microsoft Excel from the "Chart_TotalUnscheduledMaintenanceManhours.csv" file written by IMPRINT Pro. This chart captures the evolution of the unscheduled maintenance main-hours over the course of the simulation. An example 14 day scenario has been charted.

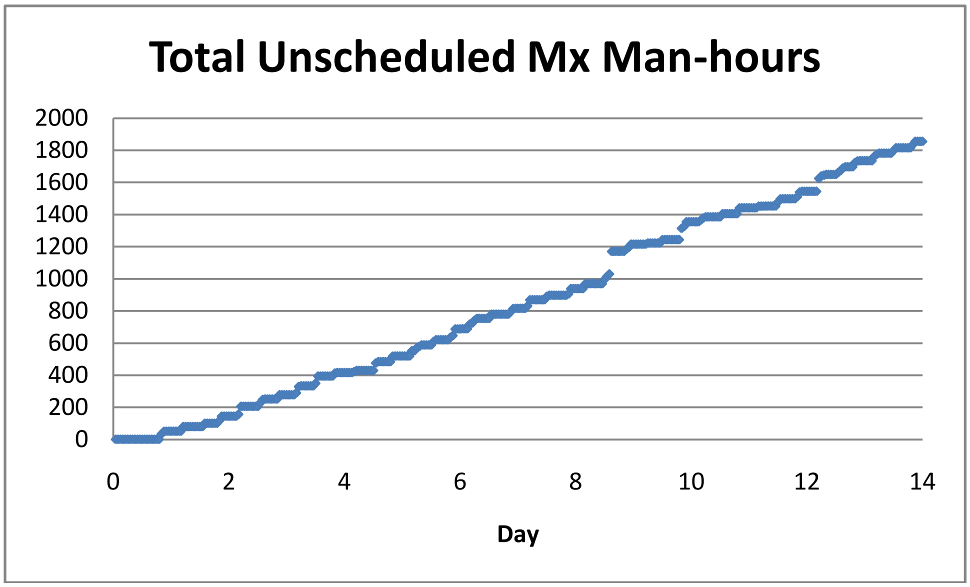


Figure 4-13. Example Unscheduled Maintenance Man-Hours Chart.

# 5 CONCLUSIONS

By the end of the yearlong MSIAC effort, the team verified the results of the improved AF HSI IMPRINT Mx Model – that is, the simulation behaved as intended and as described by SMEs. The enhancements implemented by the team over the effort improved upon the initial effort with the addition of five new weapon systems, an intuitive interface for AF analysts, dynamic charting for run-time discovery of operational metrics, and a physiological stressor for modeling fatigue. These enhancements drastically improved upon an already powerful analytical tool for assessing how human performance in various weapon system flightlines impacts the Major Command operational metrics used by the AF to assess readiness and weapon system availability.

In summary, the results provided by the AF HSI IMPRINT Mx Model indicate the impact of the human on operational metrics. Because the human plays such a substantial role in determining total system performance, more emphasis should be placed on the importance of HSI in the systems engineering and acquisition process. Only with weapon systems designed with the human element in mind can the Department of Defense realize its fullest potential.

# 6 REFERENCES

Air Force Instruction 21-101, Aircraft and Equipment Maintenance Management, 29 June 2006.

Air Force Instruction 23-502, Recoverable and Unusable Liquid Petroleum Products, 6 April 1994.

Air Force Instruction 63-1201, Life Cycle Systems Engineering, 23 July 2007.

Air Force Occupational Safety and Health Standard 91-25, Confined Spaces, 1 February 1998.

Aviano Air Base Instruction 21-101, Maintenance Procedures, 23 February 2006.

Bankston, B. & Key, T. White Paper on Capabilities Based Planning, 30 March 2006.

Labosky, M. and Lyndon, A. 1995 Logistics Handbook for Aircraft Maintenance Managers, AFLMA Project Number LM930352, November 1994.

Master Capabilities List 6.0, 6 September 2006.

Matishak, M. “Air Chief Approves Sweeping Study of Future Capability Gaps.” Inside the Air Force. 23 January 2006.

Renfro, R. and Newcomb D. “Air Force Capability Review and Risk Assessment (CRRA) Analytic Methodology.” Microsoft PowerPoint. 20 October 2004.

Technical Manual. TO 00-20-1. Aerospace Equipment Maintenance Inspection, Documentation, Policies, and Procedures.

Technical Manual. TO 00-25-172. Ground Servicing of Aircraft and Static Grounding/Bonding.

Technical Manual. TO 42B-1-23. Management of Recoverable and Waste Liquid Petroleum Products.

Titus, N. “Air Force CONOPS and Capabilities Based Planning.” Microsoft PowerPoint. 19 March 2004.

Woodward, W. “Measuring the Risk of Shortfalls in Air Force Capabilities.” March 2004.

# 7 APPENDICES

## 7.1 Flightline Maintenance Process Questionnaire

The team used this questionnaire, based on the flightline maintenance process indicated in Figure 7-1, to initiate discussions with Subject Matter Experts (SMEs) regarding the flightline maintenance process for their specific weapon system. The team asked SMEs to answer the questions in blue font. The results given by the SMEs laid the groundwork for the technical details of the task-network for each weapon system.

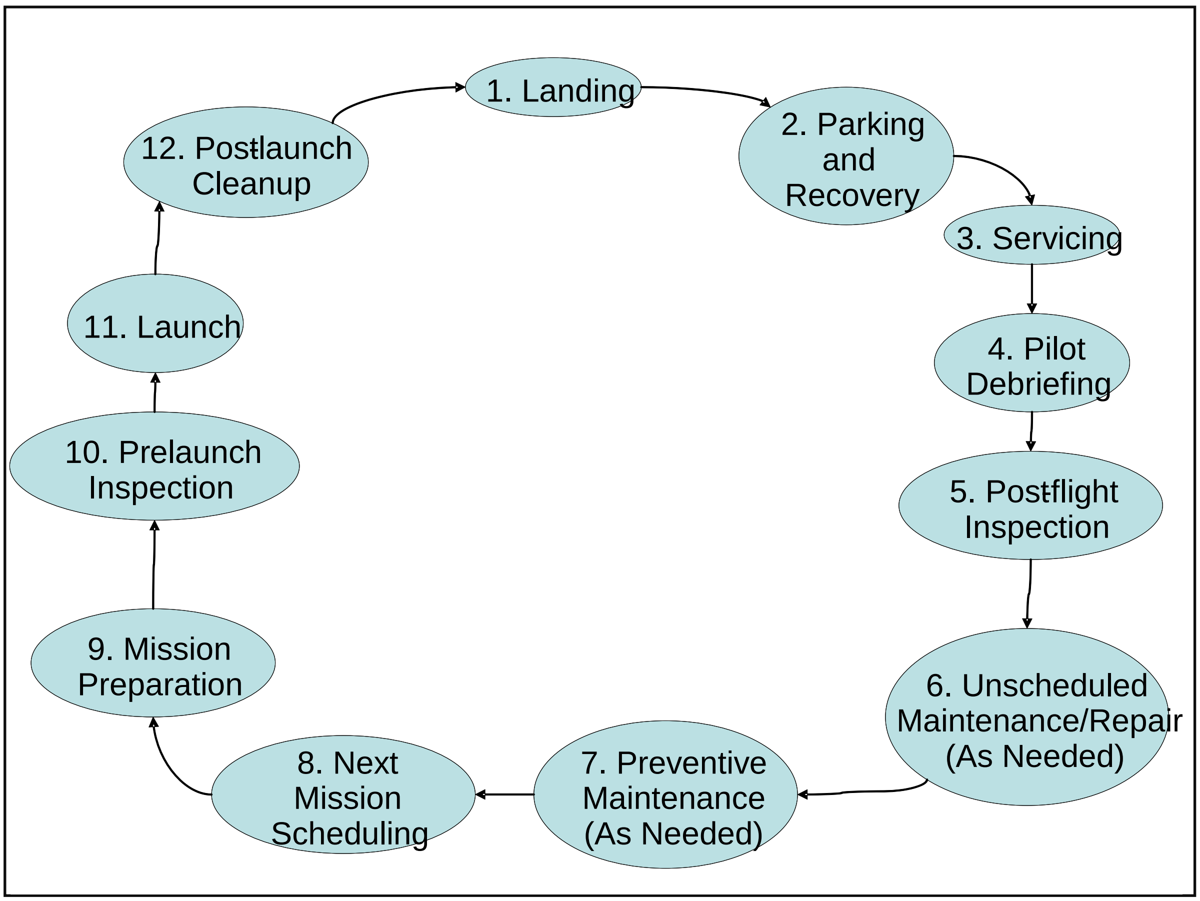


Figure 7-1. Flightline Maintenance Process
(1995 Logistics Handbook for Aircraft Maintenance Managers).

1. LANDING

1a. Maintenance personnel prepare for aircraft landing

Q1. Who is responsible (number of people and AFSC types) for recovering the aircraft upon landing?

Q2. How long (minutes) before the aircraft lands do maintenance personnel commence preparing for recovery operations?

1b. Pilot touches aircraft down on runway

Q3. How long (minutes), on average, does it take the Pilot from touchdown to exiting the runway?

1c. Pilot exits/clears the runway

1d. Safing crew safes aircraft by installing safety locking pins on munitions (more than just the munitions – check for hot brakes, walk around, missile covers, etc. rj)

Q4. Who is responsible (number of people and AFSC types) for safing the aircraft?

Q5. How long (minutes), on average, does it take to safe the aircraft?

1e. Pilot taxis aircraft to its designated parking area.

Q6. How long (minutes), on average, does it take the Pilot to taxi to the designated parking area after the aircraft has been safed?

1f. Pilot parks at designated parking spot

1g. Maintenance crew installs landing gear pins

Q7. Who is responsible (number of people and AFSC types) for installing the landing gear pins?

Q8. How long (minutes), on average, does it take the maintenance crew to install landing gear pins?

1h. Pilot powers down aircraft

Q9. How long (minutes), on average, does it take to power down the aircraft?

1i. Pilot performs post-flight inspection

Q10. How long (minutes), on average, does it take to perform a post-flight inspection?

1j. Pilot records all noted in-flight discrepancies in the aircraft forms binder

Q11. How long (minutes), on average, does it take to note in-flight discrepancies in the aircraft forms binder?

1k. Pilot leaves the aircraft parking spot to attend the maintenance debriefing

Q12. Assuming a crew chief is currently in the parking spot area at aircraft arrival, when does he/she typically leave the parking area? (e.g. after parking and recovery, after landing?)

2. PARKING AND RECOVERY

2a. Maintenance crew installs grounding wires

Q13. How long (minutes), on average, does it take the maintenance crew to install grounding wires?

Q14. Who is responsible (number of people and AFSC types) for installing grounding wires?

2b. Maintenance crew takes engine oil samples for spectrometric examination

Q15. How long (minutes), on average, does it take the maintenance crew to take engine oil samples?

Q16. Who is responsible (number of people and AFSC types) for taking engine oil samples?

2c. Maintenance crew set circuit breakers

Q17. How long (minutes), on average, does it take the maintenance crew to set circuit breakers?

Q18. Who is responsible (number of people and AFSC types) for setting circuit breakers?

2d. Maintenance crew places streamers

Q19. How long (minutes), on average, does it take the maintenance crew to place streamers?

Q20. Who is responsible (number of people and AFSC types) for placing streamers?

2e. Maintenance crew installs protective covering

Q21. How long (minutes), on average, does it take the maintenance crew to install protective covering?

Q22. Who is responsible (number of people and AFSC types) for installing protective covering?

3. AIRCRAFT SERVICING

3a. Maintenance crew checks system fluid levels and lubrication

Q23. How long (minutes), on average, does it take the maintenance crew to check system fluid levels?

Q24. Who is responsible (number of people and AFSC types) for checking system fluid levels?

3b. Maintenance crew services aircraft engine oil

Q25. How long (minutes), on average, does it take the maintenance crew to service aircraft engine oil?

Q26. Who is responsible (number of people and AFSC types) for servicing aircraft engine oil?

3c. Maintenance crew services aircraft hydraulic fluid

Q27. How long (minutes), on average, does it take the maintenance crew to service the aircraft hydraulic fluid?

Q28. Who is responsible (number of people and AFSC types) for servicing aircraft hydraulic fluid?

3d. Fuel tanks are filled based on requirements of the next scheduled mission (if known)

Q29. Who is responsible (number of people and AFSC types) for refueling the aircraft?

Q30. How long (minutes), on average, does it take to fill the fuel tanks?

Q31. Will the tanks be completely filled?

4. PILOT DEBRIEFING

4a. Debrief personnel gather aircraft reliability performance from Pilot

Q32. How long (minutes), on average, does the debriefing meeting last?

Q33. Who attends the debriefing?

5. POST-FLIGHT INSPECTION

5a. Maintenance crew performs either a i) thruflight, ii) basic post-flight, iii) combined preflight/basic post-flight, or iv) combined preflight/thruflight inspection

i) The thruflight Inspection is a between-flights inspection accomplished after each flight when a turn-around sortie or continuation flight is scheduled and a Basic Post-flight Inspection is not required.

ii) The basic post-flight occurs after the last flight of a scheduled flying period.

iii & iv) The combined inspection consolidates the requirements of the pre-flight and basic post-flight inspection into a single inspection at the end of a flying period. It is used during high temp operations to maximize generation rates.

Q34. What type of post-flight inspection is typically conducted (e.g. combined preflight/post flight inspection)?

Q35. Who is responsible (number of people and AFSC types) for conducting the post-flight inspection of the aircraft?

Q36. How long (minutes), on average, does the inspection specified last?

6. UNSCHEDULED MAINTENANCE/ REPAIR

6a. Maintenance crew performs unscheduled maintenance to repair aircraft discrepancies

- Alion Science and Technology has mean time (flight hours) between maintenance events, mean time to repair, and mean repair crew ratio, to the five digit Work Unit Code (WUC) level.

7. PREVENTIVE MAINTENANCE

7a. Maintenance crew performs actions to return the aircraft and its systems in mission ready condition

8. NEXT MISSION SCHEDULING

8a. The Aircraft is scheduled for its next mission

9. AIRCRAFT MISSION PREPARATION

9a. The fuels crew makes fuel adjustments to accommodate the scheduled mission

Q37. Will it ever be necessary to add or subtract fuel from the weapon system for the next mission? That is, is this step 9a unnecessary since the aircraft has already been topped off previously in 3) Servicing?

Q38. If fuel adjustments are necessary, how long (minutes), on average, does it take to adjust the fuel?

Q39. Who is responsible (number of people and AFSC types) for adjusting the fuel?

9b. Weapons team loads and configures munitions, chaff, and ammunition

Q40. Who is responsible (number of people and AFSC types) for loading weapons?

Q41. How long (minutes), on average, does it take to load and configure the munitions, chaff, and ammunition?

Q42. Is there any Intelligence, Surveillance, Reconnaissance (ISR) equipment loading and configuration?

Q43. If ISR equipment needs to be loaded, who is responsible (number of personnel and AFSC type) performs this task?

Q44. If ISR equipment needs to be loaded, how long (minutes), on average, does it take to load the ISR equipment?

9c. Standard mission brief to prepare pilots for upcoming mission

10. PRELAUNCH INSPECTION

10a. The crew chief performs a preflight inspection

Q45. Who is responsible (number of people and AFSC types) for performing the preflight inspection?

Q46. How long (minutes), on average, does it take to perform a preflight inspection?

10b. The Pilot performs a preflight inspection or "dash-one" inspection

Q47. How long (minutes), on average, does it take to perform a "dash one" inspection?

10c. The Pilot and maintenance crew review the aircraft forms to ensure all discrepancies are cleared and proper servicing has been done

Q48. Who is responsible (number of people and AFSC types) for reviewing the aircraft forms to ensure all discrepancies have been cleared?

Q49. How long (minutes), on average, does it take to review the aircraft forms?

11. AIRCRAFT LAUNCH

11a. <u>The Pilot enters the aircraft</u>

Q50. How long (minutes), on average, does it take the Pilot to enter the aircraft?

11b. <u>Maintenance crew disconnects support equipment and moves it away from the aircraft</u>

Q51. Who is responsible (number of people and AFSC types) for disconnecting support equipment?

Q52. How long (minutes), on average, does it take to disconnect support equipment?

11c. <u>The Pilot starts the engines</u>

Q53. How long (minutes), on average, does it take to start the engines?

11d. <u>The Pilot powers-up systems</u>

Q54. How long (minutes), on average, does it take to power up the systems?

11e. <u>The Pilot makes final system adjustments in preparation for launch</u>

Q55. How long (minutes), on average, does it take to make the final system adjustments?

11f. <u>The crew chief marshals the aircraft out of its parking spot and onto the taxiway</u>

Q56. Who is responsible (number of people and AFSC types) for marshaling the aircraft out of its parking spot to the taxiway?

Q57. How long (minutes), on average, does it take to marshal the aircraft from the parking spot to the taxiway?

11g. <u>Maintenance crew and Pilot perform an End-of-Runway inspection</u>

Q58. Who is responsible (number of people and AFSC types) for performing the end of runway (EOR) inspection?

Q59. How long (minutes), on average, does it take to perform the EOR inspection?

Q60. Who is responsible (number of people and AFSC types) for performing arming of any weaponry?

Q61. How long (minutes), on average, does it take to perform arming of weaponry?

11h. Aircraft launches and performs mission

12. POST LAUNCH CLEANUP

12a. The maintenance crew cleans up the aircraft parking location

Q62. Who is responsible (number of people and AFSC types) for performing post launch cleanup?

Q63. How long (minutes), on average, does it take to perform the post launch cleanup?

## 7.2 Simplified Flightline Maintenance Process Figure

Below, Figure 7-2 shows a refined flightline maintenance process schematic the team used to summarize the results from the questionnaires and data collection from the SMEs. The next five sub-sections reveal the results for each weapon system for this simplified figure.

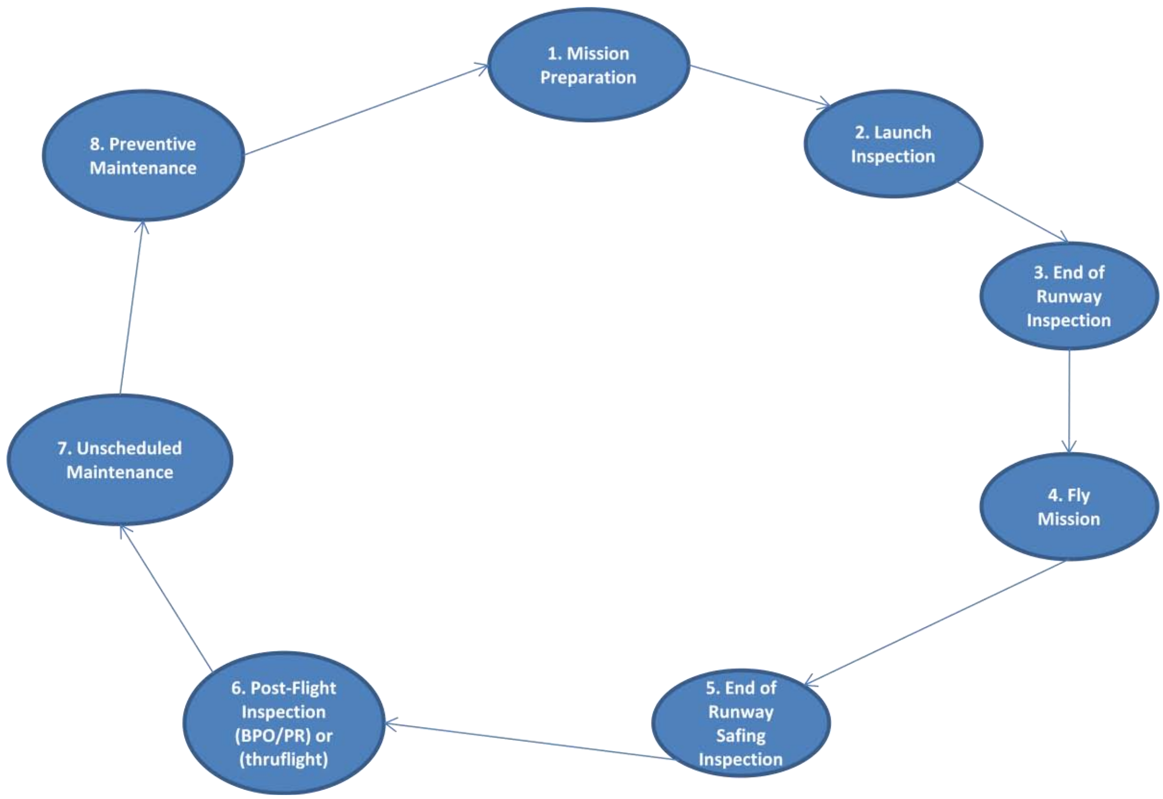


Figure 7-2. Simplified Flightline Maintenance Process Schematic.

## 7.3 C-17 Globemaster III Flightline Maintenance Subject Matter Expert Questionnaire Results

1. Mission Preparation

    1.1 Weapons crew loads munitions and chaff

    -2 weapons (weapons crew); 2 hours

    1.2 Load Cargo

    -Aerial Port Squadron; 50-75 minutes

    1.3 Weapons crew load Intelligence, Surveillance, Reconnaissance equipment

    -None (LAIRCM configured)

    1.4 Mx crew performs prior to launch walk around inspection (not in official TO -6)

    -Crew chief; 45-60 minutes

    1.5 Pilot and Mx review aircraft forms

    -Crew chief, pro-super, expeditor; 15-30 minutes

2. Launch Inspection

    2.1 Mx crew performs launch inspection (not in official TO -6)

    -Crew chief and 2 maintainers (launch crew); 35-65 minutes

    2.2 Mx crew marshals the C-17 to the taxiway

    -Crew chief and 2 maintainers (launch crew); 5-10 minutes

    2.3 Pilot taxies to EOR

    -Aircrew (Pilot, co-pilot, loadmaster); 10-20 minutes

3. End of Runway (EOR) Inspection

    3.1 Weapons crew performs EOR inspection

        -None. This is performed by the aircrew

4. Fly Mission

    4.1 Pilot launches C-17
    4.2 Pilot conducts mission
    4.3 Pilot touches down and lands C-17

5. EOR Safing Inspection

    5.1 Weapons crew performs EOR safing inspection

        -None. This is performed by the aircrew

    5.2 Pilot taxies to parking spot

        - Aircrew (Pilot, co-pilot, loadmaster); 10-20 minutes

6. Recovery Inspection

    6.1 Mx crew performs recovery inspection (not in official TO -6)

        -Crew chief and two maintainers; 45-60 minutes (team stays until cargo is downloaded)

    6.2 Unload cargo

        -Aerial Port Squadron; (included in 6.1)

    6.3 Mx crew and fuels crew refuels C-17

        - Crew chief and two maintainers; 30-55 minutes

7. Post-flight Inspection

    7.1 Mx crew performs Preflight/Basic Post-flight (PR/BPO)

-Crew chief and Maint tech; 2.5 - 3 hours (PR/BPO)

8. Unscheduled Maintenance

    8.1 Mx crew performs unscheduled maintenance

        -Mx crew; variable minutes

    8.2 Mx crew orders supply part

        -Mx crew; variable minutes

9. Preventive Maintenance

    9.1 Mx crew performs preventive maintenance

        -Mx crew; variable minutes

## 7.2 CV-22 Osprey Flightline Maintenance Subject Matter Expert Questionnaire Results

1. Mission Preparation

1.1 Weapons crew loads munitions and chaff

-2 weapons; 45-60 minutes

1.2 Load Cargo

-Flight engineers; 1 hour for mission auxiliary tanks (depends on cargo)

1.3 Load ISR

-None

1.4 Load ECM

-None

1.5 Mx crew performs prior to launch walk around inspection

-Crew chief; 25-30 minutes

1.6 Aircrew and Mx review aircraft forms

-Crew chief; 5 minutes

2. Launch Inspection

2.1 Mx crew performs launch inspection

-Crew chief and b-man; 25 minutes

2.2 Mx crew marshals the CV-22 to the taxiway

-Crew chief and b-man; 30 seconds

2.3 Aircrew taxies to EOR

-Aircrew; 2-3 minutes

3. End of Runway (EOR) Inspection

    3.1 Weapons crew performs EOR inspection

    -None

4. Fly Mission

    4.1 Aircrew launches CV-22
    4.2 Aircrew conducts mission
    4.3 Aircrew touches down and lands CV-22

5. EOR Safing Inspection

    5.1 Weapons crew performs EOR safing inspection

    -None

    5.2 Aircrew taxies to parking spot

    -Aircrew; 2-3 minutes

6. Recovery Inspection

    6.1 Mx crew performs recovery inspection

    -Crew chief and b-man; 10 minutes

    6.2 Unload cargo

    -Flight engineers; 1 hour for mission auxiliary tanks (depends on cargo)

    6.3 Mx crew and fuels crew refuels CV-22

    -1 Crew chief; 3 Mx techs; 10-45 minutes

7. Post-flight Inspection

    7.1 Mx crew performs Preflight/Basic Post-flight (PR/BPO) or thruflight inspection

-2 Crew chiefs; 240 – 300 minutes (PR/BPO)

8. Unscheduled Maintenance

    8.1 Mx crew performs unscheduled maintenance

    -Mx crew; variable minutes

    8.2 Mx crew orders supply part

    -Mx crew; variable minutes

9. Preventive Maintenance

    9.1 Mx crew performs preventive maintenance

    -None

## 7.3 F-15E Strike Eagle Flightline Maintenance Subject Matter Expert Questionnaire Results

1. Mission Preparation

   1.1 Weapons crew loads munitions and chaff

   -3 weapons; 15 min – 1 hour – 3 hours

   1.2 Weapons crew load Intelligence, Surveillance, Reconnaissance equipment

   -None

   1.3 Mx crew performs prior to launch walk around inspection

   -Crew chief; 25-30 minutes

   1.4 Pilot and Mx review aircraft forms

   -Crew chief; 2-5 minutes

2. Launch Inspection

   2.1 Mx crew performs launch inspection

   -Crew chief and b-man; 25 minutes

   2.2 Mx crew marshals the F-15E to the taxiway

   -Crew chief and b-man; 30 seconds

   2.3 Pilot taxies to EOR

   -Pilot; 2-3 minutes

3. End of Runway (EOR) Inspection

   3.1 Weapons crew performs EOR inspection

   -2 crew chiefs and 2 weapon techs; 7 - 15 minutes

4. Fly Mission

    4.1 Pilot launches F-15E
    4.2 Pilot conducts mission
    4.3 Pilot touches down and lands F-15E

5. EOR Safing Inspection

    5.1 Weapons crew performs EOR safing inspection

        -2 weapon techs; 3-5 minutes

    5.2 Pilot taxies to parking spot

        -Pilot; 2-3 minutes

6. Recovery Inspection

    6.1 Mx crew performs recovery inspection

        -Crew chief and b-man; 10 minutes

    6.2 Mx crew and fuels crew refuels F-15E

        -Crew chief; 20 - 25minutes

7. Post-flight Inspection

    7.1 Mx crew performs Preflight/Basic Post-flight (PR/BPO)

        -Crew chief; 2-3 hours (PR/BPO)

8. Unscheduled Maintenance

    8.1 Mx crew performs unscheduled maintenance

        -Mx crew; variable minutes

    8.2 Mx crew orders supply part

        -Mx crew; variable minutes

9. Preventive Maintenance

   9.1 Mx crew performs preventive maintenance

      -Mx crew; variable minutes

## 7.4 MQ-1 Predator Flightline Maintenance Subject Matter Expert Questionnaire Results

1. Mission Preparation

   1.1 Weapons crew loads munitions and chaff

   -2 weapons (2W1X1), 1 safety monitor; 5 minutes

   1.2 Weapons crew load Intelligence, Surveillance, Reconnaissance equipment

   -Crew chief (2A3X3), Avi (2A3X2), or Weapons; 1 hour; “ISR is active until the UAV is inop”

   1.3 Mx crew performs prior to launch walk around inspection

   -Pro-super or LRE crew (0011U3A, 011U3B, 011U3Y); 3-5 minutes for LRE crew

   1.4 Launch and Recovery Element (LRE) performs Dash-1 Inspection

   -LRE crew; 10 minutes

   1.5 LRE reviews UAS forms

   -Crew chief or avi and LRE; 5 minutes

   1.6 LRE starts UAS

   -Pilot; seconds

2. Launch Inspection

   2.1 LRE crew performs launch inspection

   -LRE; 10-30 minutes

   2.2 Mx crew marshals the UAS to the taxiway

   -Crew chief or Avi; 30 seconds

2.3 LRE taxies to EOR

-LRE; 1-2 minutes

3. End of Runway (EOR) Inspection

3.1 Weapons crew performs EOR inspection

-Weapons crew; 5 minutes

4. Fly Mission

4.1 LRE launches UAS
4.2 Ground Control Station (GCS) conducts mission
4.3 LRE touches down and lands UAS

5. EOR Safing Inspection

5.1 Weapons crew performs EOR safing inspection

-Weapons crew; 5 minutes

5.2 LRE taxies to parking spot

-LRE; 1-2 minutes

6. Recovery Inspection

6.1 Mx crew and fuels crew refuels UAS

-2 Crew chiefs and Avi; 30 minutes

7. Post-flight Inspection

7.1 Mx crew performs Preflight/Basic Post-flight (PR/BPO)

-Crew chief or Avi; 1.5 hours (PR/BPO)

7.2 Weapons crew performs PR/BPO

-Weapons crew; 30 minutes (PR/BPO)

8. Unscheduled Maintenance

    8.1 Mx crew performs unscheduled maintenance

        -Mx crew; variable minutes

    8.2 Mx crew orders supply part

        -Mx crew; variable minutes

9. Preventive Maintenance

    9.1 Mx crew performs preventive maintenance

        -Mx crew; variable minutes

## 7.5 MQ-9 Reaper Flightline Maintenance Subject Matter Expert Questionnaire Results

1. Mission Preparation

1.1 Weapons crew loads munitions and chaff

-2 weapons (2W1X1), 1 safety monitor; 15-20 minutes

1.2 Weapons crew load Intelligence, Surveillance, Reconnaissance equipment

-Crew chief (2A3X3), Avi (2A3X2), or Weapons; 1 hour; “ISR is active until the UAV is inop”

1.3 Mx crew performs prior to launch walk around inspection

-Pro-super or LRE crew (0011U3A, 011U3B, 011U3Y); 3-5 minutes for LRE crew

1.4 Launch and Recovery Element (LRE) performs Dash-1 Inspection

-LRE crew; 10 minutes

1.5 LRE reviews UAS forms

-Crew chief or avi and LRE; 5 minutes

1.6 LRE starts UAS

-Pilot; seconds

2. Launch Inspection

2.1 LRE crew performs launch inspection

-LRE; 10-30 minutes

2.2 Mx crew marshals the UAS to the taxiway

-Crew chief or Avi; 30 seconds

2.3 LRE taxies to EOR

-LRE; 1-2 minutes

3. End of Runway (EOR) Inspection

3.1 Weapons crew performs EOR inspection

-Weapons crew; 5-10 minutes

4. Fly Mission

4.1 LRE launches UAS
4.2 Ground Control Station (GCS) conducts mission
4.3 LRE touches down and lands UAS

5. EOR Safing Inspection

5.1 Weapons crew performs EOR safing inspection

-Weapons crew; 5-10 minutes

5.2 LRE taxies to parking spot

-LRE; 1-2 minutes

6. Recovery Inspection

6.1 Mx crew and fuels crew refuels UAS

-2 Crew chiefs and Avi; 30 minutes

7. Post-flight Inspection

7.1 Mx crew performs Preflight/Basic Post-flight (PR/BPO)

-Crew chief or Avi; 1.5 hours (PR/BPO)

7.2 Weapons crew performs PR/BPO

-Weapons crew; 30 minutes (PR/BPO)

8. Unscheduled Maintenance

    8.1 Mx crew performs unscheduled maintenance

        -Mx crew; variable minutes

    8.2 Mx crew orders supply part

        -Mx crew; variable minutes

9. Preventive Maintenance

    9.1 Mx crew performs preventive maintenance

        -Mx crew; variable minutes

## 7.6 SAFTE: Modeling Warfighter Fatigue in IMPRINT Pro

# The SAFTE Plugin for IMPRINT Pro:
# Incorporation of a Model of Fatigue

*Contract Order Number:*

**DAAD19-01-C-0065**

**Task Order 46, Task 12**

*Date of Preparation:*

**24 January 2008**

*Prepared for:*

**U.S. Army Research Laboratory,**

**Human Research and Engineering Directorate (ARL-HRED)**

*Prepared by:*

**Alion Science and Technology, MA&D Operation**

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Boulder, CO  80301-2477

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### 1.0 Introduction

1.1 Program Overview

This effort was sponsored by the Army Research Laboratory, Human Research and Engineering Directorate (ARL-HRED) and performed over a three-month period under contract DAAD19-01-C-0065, Task Order 46, "Soldier Centered Design Tools." This report summarizes the background, technologies involved, technical approach, and results.

The underlying objective of this effort was to provide an improved model of human fatigue to IMRPINT Pro (Improved Performance Research Integration Tool). A methodology and supporting data were developed into numerical and logic based algorithms by Steven R. Hursh, Ph.D. of Science Applications International Corporation (SAIC) and Johns Hopkins University School of Medicine. Testing of the implementation of this model of Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE) was performed by the Air Force. The result was validation and acceptance by the user community of the leading model of the effects of fatigue on human performance. The effort undertaken here consisted of integration of the algorithms that encapsulate the SAFTE model for use within IMPRINT Pro, a government owned set of automated aids to assist analysts in conducting human performance analyses. IMPRINT Pro provides the means for estimating manpower, personnel, and training (MPT) requirements and constraints for new weapon systems very early in the acquisition process.

This task mainly consisted of porting the SAFTE algorithms into a package that would allow their easy use within IMPRINT Pro models. The result is a SAFTE plugin that seamlessly integrates with IMPRINT Pro to allow simulation of the effect of fatigue on warfighter performance.

1.2 Report overview

This report about the SAFTE plugin provides the following:

- background,
- technologies involved,
- assumptions and limitations,
- the SAFTE plugin user interface, and
- the effects of fatigue modeled by the SAFTE plugin.

First, we will provide a brief description of the SAFTE model and its implementation into an algorithm. Next, in Section 2 we will introduce the technologies involved in realizing this effort. Finally, in Section 3 is a description of the use of the SAFTE plugin and its user interface.

1.3 Background

This project leveraged the SAFTE model and its implementation into the Fatigue Avoidance Scheduling Tool (FAST) created and developed under the direction of Steven R. Hursh, Ph.D. in work he did for the Department of Defense and others. Here's what Dr. Hursh has to say about FAST.

The Fatigue Avoidance Scheduling Tool (FAST) is a software decision aid designed to assess and forecast performance changes induced by sleep restriction and time of day. This information is intended to help managers and individuals design work and sleep schedules that will reduce the risk of fatigue and fatigue induced errors. However, SAIC and NTI warn users that the predictions from this software may not be accurate for any given individual or situation. For a variety of reasons, no planning software, including FAST, can predict fatigue or fatigue induced errors in all cases or for all individuals. Fatigue management involves many initiatives to reduce fatigue and the FAST system is just one useful component of an overall management approach to fatigue avoidance. Among the many factors that limit the ability of FAST to accurately assess fatigue in all cases are the following:

1. The employer can only give the employee sufficient time to get sleep between shifts, but cannot guarantee that the employee uses that time to get optimal sleep. The tool can only assume that the employee follows instructions to sleep and, therefore, predictions are uncertain. Even when the employee takes sleep, the time of day or the environmental conditions may prevent the sleep from being optimally restorative of performance.

2. Not all employees need the same amount of sleep to be effective. The model assumes that all people need 8 hours of sleep per day. Any given individual may need more or less than that normative value to remain fully alert on the job.

3. Some employees may have sleep disorders that FAST cannot take into account, such as narcolepsy or sleep apnea. Some employees may use drugs or medications that alter alertness in ways that FAST cannot take into account.

4. Not all tasks require the same degree of attention. The tool currently predicts "performance of an average person on a task especially sensitive to fatigue" and may over or under estimate effectiveness of a particular person on a particular task. The tool can give the user an estimate of the range of population error, but cannot predict where a particular person falls within that range. Nevertheless, the tool makes reasonable "ordinal" predictions among schedules for most people.

5. The tool predicts departures of performance of an average person from a normal-rested "baseline". A prediction of 100% effectiveness is not error free performance; it means that performance is 100% of normal, a level that still has some risk of error.

6. The tool only predicts average performance such that steps can be taken to reduce the likelihood of error, but it cannot guarantee that for any particular employee under some specific set of circumstances, an unusual lapse in attention might occur that could, under unfavorable conditions, lead to an error, incident, or accident.

7. The tool can only forecast the effects of sleep and circadian rhythms on performance and cannot account for other factors that alter performance such as training, experience, motivation, environmental conditions, stress, boredom, illness, or any of a variety of other variables known to affect performance besides fatigue.

8. Fatigue can result from factors other than restricted sleep or circadian disruption such as excessive workload, medications, chronic fatigue syndrome, exercise, hypoxia,

acceleration, temperature, or infection. These factors are not currently considered in FAST predictions.

The motivation behind the SAFTE model was, according to Dr. Hursh, "to develop a practical operational tool to provide near term assistance to reduce the consequences of fatigue in our fighting forces based on a valid fatigue model informed by current and future scientific research." "The SAFTE model integrates quantitative information about (1) circadian rhythms in metabolic rate, (2) cognitive performance recovery rates associated with sleep, and cognitive performance decay rates associated with wakefulness, and (3) cognitive performance effects associated with sleep inertia to produce a 3-process model of human cognitive effectiveness."

Through his work, a simulation model for SAFTE was developed and is shown in Figure 1.

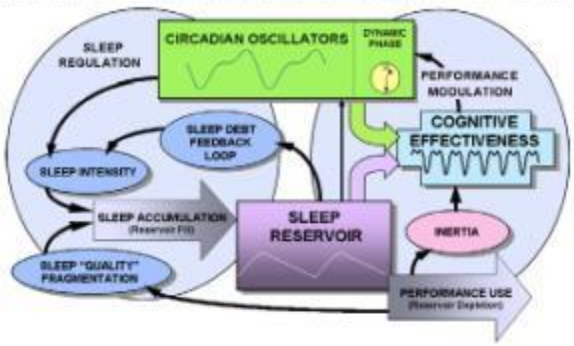



**Figure 1. Schematic of the SAFTE™ Model.**

This model combines three areas of validation: task performance predictions, safety and accident prediction, and subjective fatigue predictions. By combining two major components of human performance (sleep reservoir balance and circadian rhythm of alertness – see Figure 2) Dr. Hursh created an algorithm that would predict cognitive effectiveness as shown in an example of typical performance from eight hours of sleep per day (Figure 3).

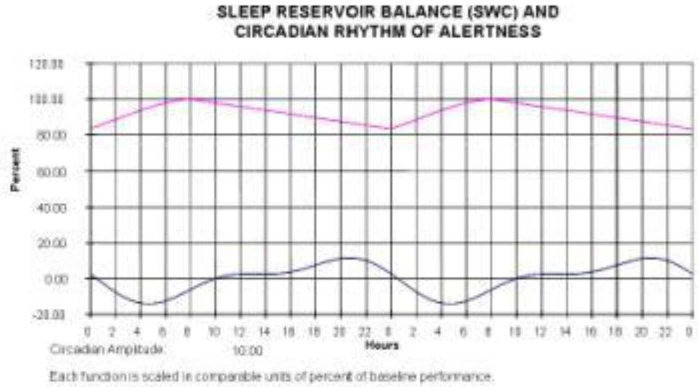



**Figure 2. Two major components of performance.**

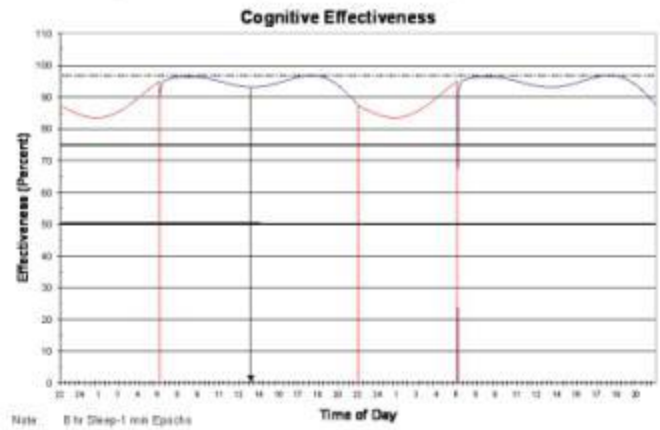



**Figure 3. Typical performance prediction from 8 hours sleep.**

Attributes related to sleep and fatigue not currently included in the SAFTE model include:

- Stimulant performance enhancement
- Sedative sleep enhancement
- Naps and sleep schedule optimization
- Individual variance

A verification and analysis of the fatigue model was performed in the fall of 2005 by the Air Force Research Laboratory - Human Effectiveness Directorate (AFRL-HED) at Books City-Base, Texas. There findings can be found in the referenced paper.

## 2.0 Technologies Involved

IMPRINT Pro is a modeling tool with a large number of widely varying capabilities to allow a user to analyze both complex and simple missions that involve warfighters (i.e., humans.) As a modeler using IMPRINT Pro it is highly desirable to have user interfaces that are intuitive and easy to use. To that end, the incorporation of the algorithms that constitute the SAFTE model was constructed using "plugin" technology that contained its own user interface. This plugin capability allows easy existence, or non-existence, of customized applications.

Using this plugin architecture, it was possible to encapsulate the software code that implements Dr. Hursh's SAFTE model in a module that would be directly compatible with IMPRINT Pro.

## 3.0 The SAFTE Plugin

The SAFTE features are made present or absent by either including or omitting, respectively the associated plugin file (a .dll file). The SAFTE plugin has a filename of "ARL.Plugins.Safte.dll" and when this file is present in the folder in which IMPRINT Pro resides it will be automatically recognized during program startup and made available to the user. One cue easily seen within the IMPRINT Pro interface will be an icon of a sleeping man  in the Windows area (In Figure 4 note along the left edge, included in the collection of icons under Windows, one labeled Fatigue.)

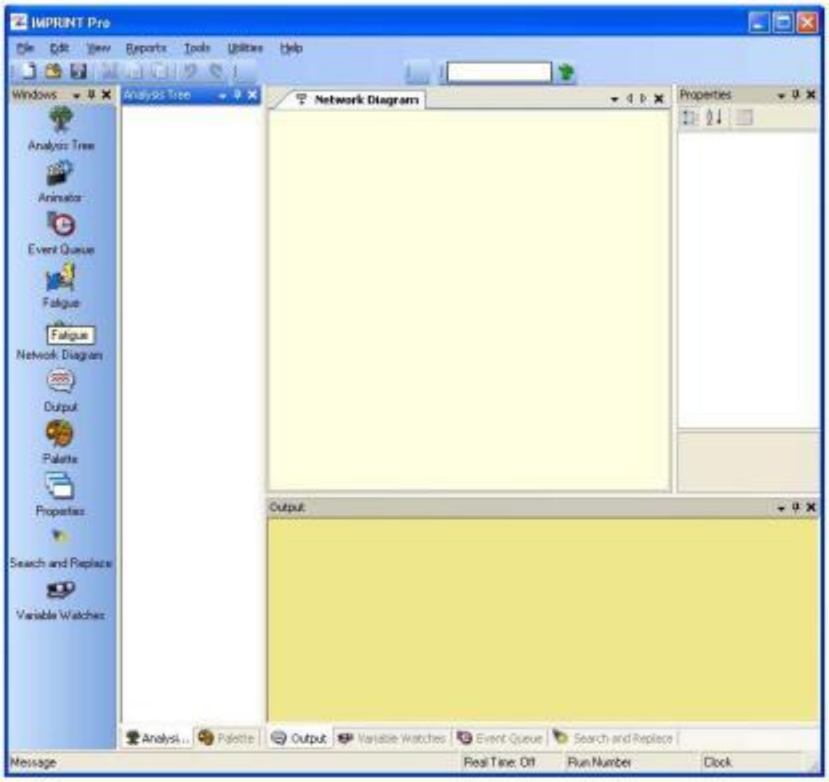



**Figure 4. IMPRINT Pro with Fatigue Plugin.**

3.1 Model Assumptions and Limitations

Not all features and capabilities present in FAST were made available to the user via the plugin. This was done to provide the desired functionality of fatigue without over-burdening the IMPRINT user. Future efforts could expose additional portions as the need or desires arise.

The assumptions and known limitations of the SAFTE model as implemented in the plugin for IMPRINT Pro are as follows:

- These effects are only provided to the Operator modeling portion of IMPRINT Pro. The SAFTE plugin will not affect the Maintainer portion.
- Each Warfighter (more precisely, every non-automated Operator) in a model will be affected by the SAFTE model. That is, there is not a capability to activate it for some Warfighters and not for others.
- Every Operator within an Analysis will use the same SAFTE parameter settings

- Once an Analysis starts, it is assumed that none of the Operators sleep or take a nap.
- An artificial lower limit has been placed on the reduction in effectiveness. Reasoning is that at such extreme levels of fatigue and sleep deprivation, the basic assumptions and supporting data of the model itself are no longer valid. While it is unknown at what level the model of effectiveness becomes invalid, for current purposes it has been assumed to be 1%.
- Assumes that each mission starts at 0700 after going to sleep at 2300 the evening before.
- There are a fixed set of sleep histories to choose from

Shown in Figure 5 is a representative plot of the change in percent of effectiveness as the time since getting some sleep. In this example, each night for the past four days the person has slept eight hours and the plot shows that each day his effectiveness is restored to 100%. At the end of the forth day (depicted as the vertical black line at around 4,800 minutes) this person wakes up from eight hours of sleep and the effects of lack of sleep begin. At 5,760 minutes (the end of four 24-hour days) instead of getting some sleep and recovering to full effectiveness he continues on with no additional sleep. After about four more days his performance effectiveness is at zero and basically stays there until additional sleep is obtained. (It is at this lower effectiveness that a lower boundary of 1% effectiveness has been placed.)


**Figure 5. Effectiveness modeled by SAFTE after 8 hours of sleep per day for the past 4 days.**

A similar plot is shown in Figure 6 when only 1 hour of sleep is taken per night for the previous four nights.. Notice that the effectiveness upon the end of the forth day (5,760 minutes) is only about 9% as compared to 90% when getting 8 hours of sleep per night.

**Figure 6. Effectiveness modeled by SAFTE after 1 hour of sleep per day for the past 4 days.**

3.2 SAFTE User Interface

Applying the effects of fatigue within an IMPRINT Pro model can be controlled through Fatigue user interface. The user is allowed to select one of five predefined sleep histories. These sleep histories are used to determine the initial state of the operators when the analysis begins. Recall that once the analysis model begins none of the operators obtain any additional rest and thus his effectiveness will continue to degrade.

The interface that allows selection of user defined parameters is activated by clicking on the Fatigue icon in the Windows area of the IMPRINT Pro user interface. Upon clicking that icon the Fatigue user interface (See Figure 7) is exposed. By default a sleep history of six hours of sleep per day for the past 4 days is selected. The sleep/activity histories are as follows:

- 1 hour of sleep per day for the past 4 days
- 2 hours of sleep per day for the past 4 days
- 4 hours of sleep per day for the past 4 days
- 6 hours of sleep per day for the past 4 days
- 8 hours of sleep per day for the past 4 days

The user has to option to enable advanced features to further alter the sleep/activity history. To do this the user checks the "Enable Advanced Options" box and that enables the additional features. The sleep/activity history selected using the above described predefined setting will be used as a starting point. Using this advanced feature allows the user to set the following parameters:

- Start Day – this is the day that the model will start and thus sleep will cease

- Start Time – this is the time of day that the selected Starting State begins. Only whole hours can be selected.
- Starting State – this set the state that operators will be in when the simulation starts. It can be set to either Asleep or Awake
- Sleep/Wake Pattern – this portion of the interface can be used to define the number of hours spent asleep and awake prior to the start of the simulation

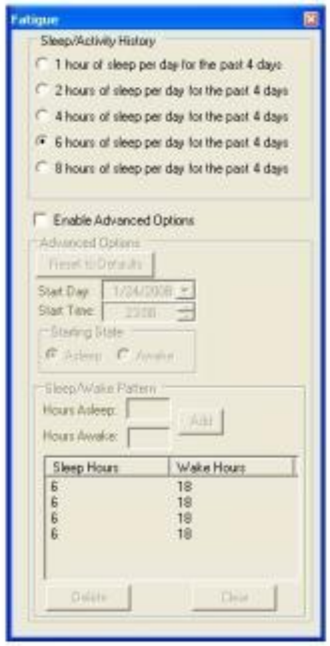



**Figure 7. SAFTE plugin User Interface.**

3.3 Operator Performance Due to Fatigue

Activation of the SAFTE model results in the modification of the time to perform a task. As each operator in an analysis model reaches a task the time to perform the task is determined. With the inclusion of the SAFTE plugin an additional modifier due to fatigue also modifies the task time. The percent effectiveness predicted by the SAFTE model is used to degrade the time to perform the task as follows:

$t' = t_0 * 1/E_F(t)$

where,

$t_0$ is the IMPRINT provided time to perform the task

$E_F(t)$ is the percent effectiveness due to fatigue at time t,

t' is the modified time to perform the task as predicted by SAFTE.

## 4.0 Results

Through this program we were able to implement effects of human fatigue on task performance for Operators as Warfighters within analyses conducted using IMPRINT Pro. The onset of fatigue can be studied by altering the sleep/activity pattern prior to commencing the mission.

## 5.0 References


Eddy, D.R. and Hursh, S.R. (2001). *Fatigue Avoidance Scheduling Tool (FAST)*. AFRL-HEBR-TR-2001-0140, SBIR Phase I Final Report, Human Effectiveness Directorate Biodynamics and Protection Division, Flight Motion Effects Branch, Brooks AFB TX 78235-5105.

Hursh, S.R. (2003). Sleep, Activity, Fatigue and Task Effectiveness (SAFTE) Model

Fatigue Avoidance Scheduling Tool (*FAST*TM). ARFL: Science and Technology for Tomorrow's Aerospace Force, Warfighter Fatigue Countermeasures., Submitted for PA approval, Jan 2003.

Chaiken, S.R. (2005). *A Verification and Analysis of the USAF/DOD Fatigue Model and Fatigue Management Technology*. AFRL-Human Effectiveness Directorate, Biosciences and Protection Division, Fatigue Countermeasures Branch, Brooks City-Base, TX 78235.

## 7.7 AF HSI IMPRINT Pro Maintenance Model Introductory Flier

**U.S. Air Force**
**Human Systems Integration Maintenance Model Enhancements**
**in the**
**Improved Performance Research Integration Tool**

### ***Improved Performance Research Integration Tool (IMPRINT) Pro***

The U.S. Army Research Laboratory, Human Research & Engineering Directorate developed the Improved Performance Research Integration Tool (IMPRINT) Pro to support Manpower and Personnel Integration (MANPRINT) and Human Systems Integration (HSI). IMPRINT Pro is a dynamic, stochastic, discrete event network modeling tool designed to help assess the interaction of Warfighter and system performance throughout the system lifecycle--from concept and design to field testing and system upgrades.

IMPRINT Pro can be used to help set realistic system requirements; to identify soldier-driven constraints on system design; and to evaluate the capability of available manpower and personnel to effectively operate and maintain a system under environmental stressors. IMPRINT Pro is also used to target Warfighter performance concerns in system acquisition; to estimate Soldier-centered requirements early, and to make those estimates count in the decision making process. As a research tool, IMPRINT Pro incorporates task analysis, workload modeling, performance shaping and degradation functions and stressors, and embedded personnel characteristics data.

In previous versions IMPRINT, as it was named, focused solely on Army missions. In its latest version, IMPRINT Pro is a joint service tool with the capability to examine Army, Navy, Air Force, and Marine systems.

IMPRINT Pro is used to model both crew and individual performance. For some analyses, workload profiles are generated so that crew-workload distribution and individual-system task allocation can be examined. In other cases, maintainer utilization is assessed along with the resulting system availability. Also, using embedded algorithms, IMPRINT Pro models the effects of personnel characteristics, training frequency, and environmental stressors on the overall system performance. Manpower requirements estimates can be generated for a single system, a unit, or an entire service. The output from IMPRINT Pro can be used as the basis for estimating manpower lifecycle costs.

## *What Can You Do with IMPRINT Pro?*

IMPRINT Pro is a powerful analysis tool that can be used to:

- Set realistic system requirements
- Identify future manpower and personnel constraints
- Evaluate operator and crew workload (auditory, cognitive, gross motor, fine motor, speech, tactile, and visual)
- Test alternate system-crew function allocations
- Assess required maintenance man-hours
- Assess performance during extreme climate conditions (from extreme cold to extreme heat)
- Examine operator performance as a function of personnel aptitude characteristics and training frequency
- Evaluate the effects of whole body vibration on Warfighter performance
- Identify areas of the system under evaluation to focus test and evaluation resources
- Quantify human system integration risks to mission performance to support milestone review
- Estimate life-cycle cost of system design
- Represent humans in federated simulations
- Conduct force projections of service personnel in future years by various categories
- Evaluate the impact of sea state on Warfighters operating on marine vessels

## *US Air Force HSI Maintenance Model Enhancements in IMRINT Pro*

The USAF has developed a human performance simulation – called the "AF HSI Maintenance Model" - within IMPRINT Pro of the mission generation process and the flightline maintenance process for the following six USAF weapon systems:

- C-17 Globemaster III
- CV-22 Osprey
- F-15C Eagle
- F-15E Strike Eagle
- MQ-1 Predator
- MQ-9 Reaper

An intuitive graphical user interface to the AF HSI Maintenance Model provides a simple and effective method for conducting "What If" analyses on hypothetical mission scenarios to aid the squadron commander in mission planning. The AF HSI Maintenance Model allows an analyst to predict the following operational metrics:

- Sortie generation rate

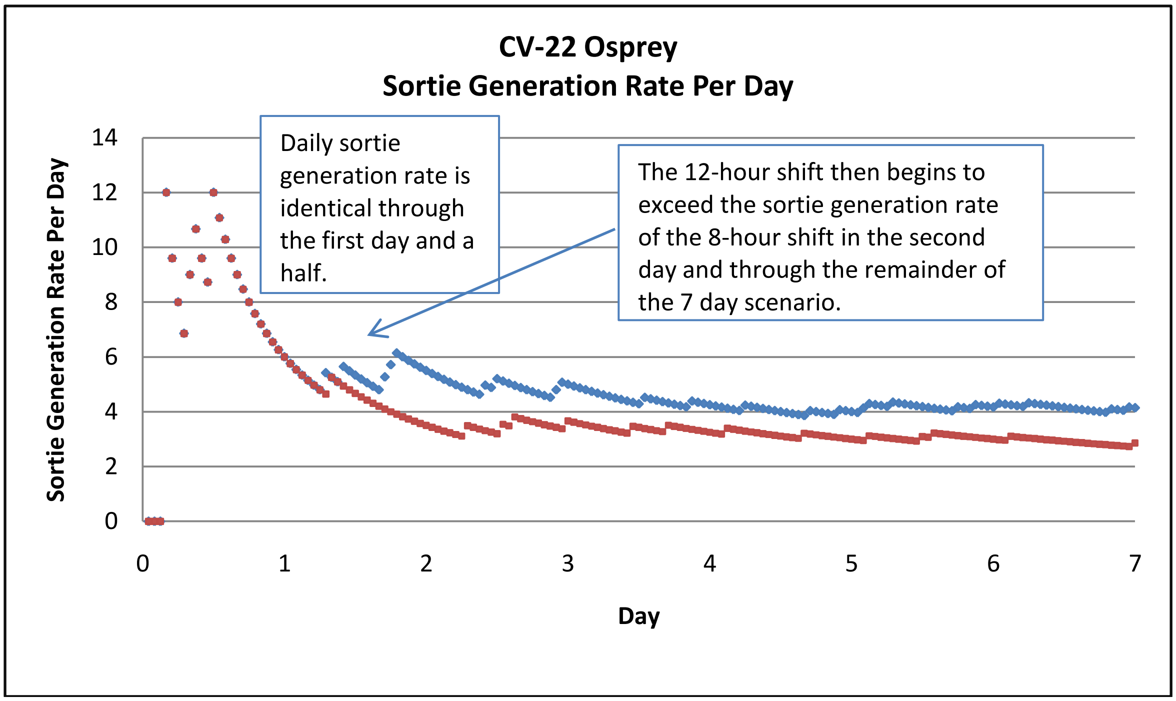
- Mission capability rate (fully mission capable, non mission capable, total non mission capable maintenance, total non mission capable supply, total non mission capable both)
- Scheduled maintenance man-hours (routine)
- Unscheduled maintenance man-hours (unplanned)
- Unscheduled maintenance events by work unit code, event time, and repair crew
- Warfighter Interactions with Environment, Safety, and Occupational Health (ESOH) Hazards
- Administrative delay time
- Flying schedule effectiveness

The following independent variables can be specified and manipulated to enhance the realism of the analyses:

- Operational tempo (OPSTEMPO) defining when aircraft fly and for how long
- Aircraft component reliability (how often components fail) and maintainability (duration and crew size to repair a component)
- Manpower (number of crew chiefs, maintenance technicians, and weapon technicians available to support the flightline maintenance process)
- Force structure (number of weapon systems available to fly missions)
- Supply distribution timelines (how often a supply part is required and how long it takes to receive from supply)
- Fatigue (the amount of sleep that the flightline maintenance team has received the four days prior to beginning the simulation)
- Abort and attrite rate

**Q: Over a 7 day period can I generate more sorties using an 8-hour shift than a 12-hour shift?**

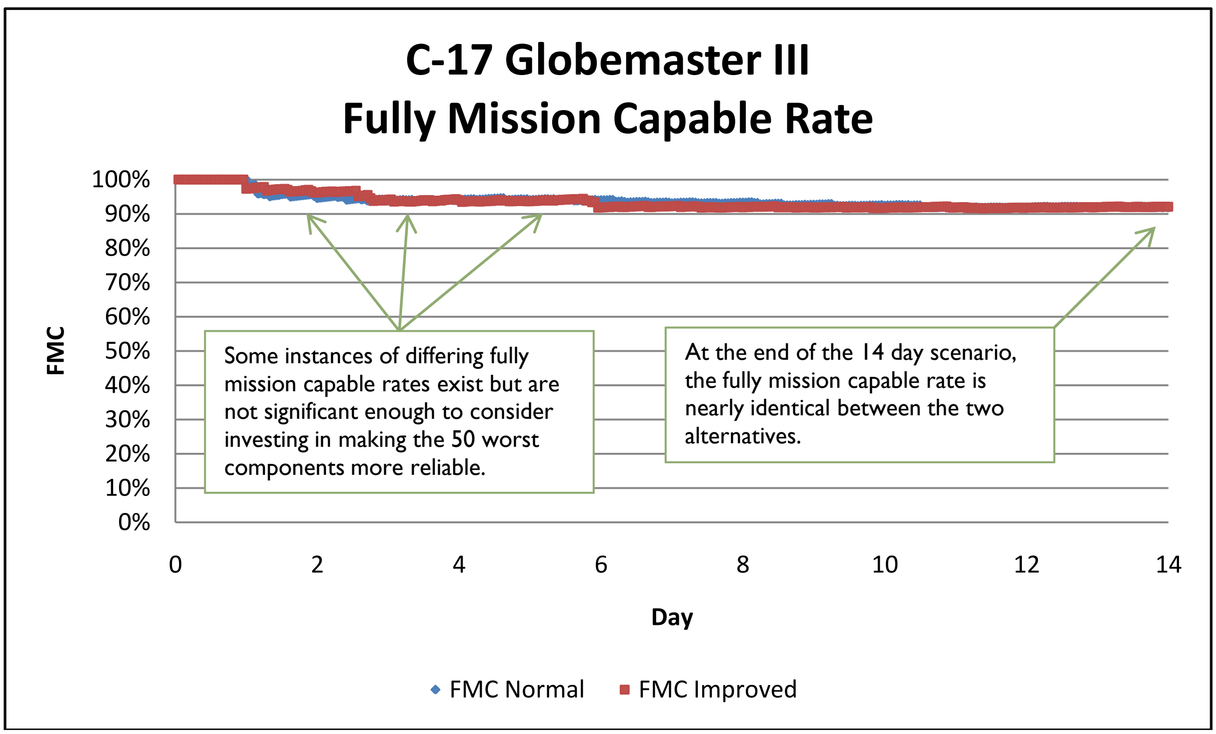
**(Future Possibility: What specialist mix will give me the best sortie generation rate outcome?)**




**Notional chart of the CV-22 Osprey sortie generation rate per day contrasting a 12-hour manning shift with an 8-hour manning shift for a 7 day scenario.**

**A: No. Due to the decreased availability of manpower in the 8-hour shift, the daily sortie generation rate drops by one – from four to three sorties per day – when compared to the 12-hour shift at the end of a seven day scenario.**

**Q: How much will my fully mission capable rate improve if the reliability of the 50 worst components is upgraded by 100% (i.e. made twice as reliable with capital investments in component manufacturers)?**




**Notional chart of C-17 Fully Mission Capable rate for a 7 day scenario contrasting normal maintainability versus improved maintainability.**

**A: At the end of the 14 day scenario, the fully mission capable rate improves by only 0.3% when improving the 50 least reliable components by 100% in a 14 day scenario. It**

**may not be cost effective to increase the reliability of these components.**

**Q: Can removing the requirement to service the engine oil in the 25 hour engine inspection reduce the maintainer's interaction with Environment, Safety, and Occupational Health hazards and reduce impacts to the environment?**

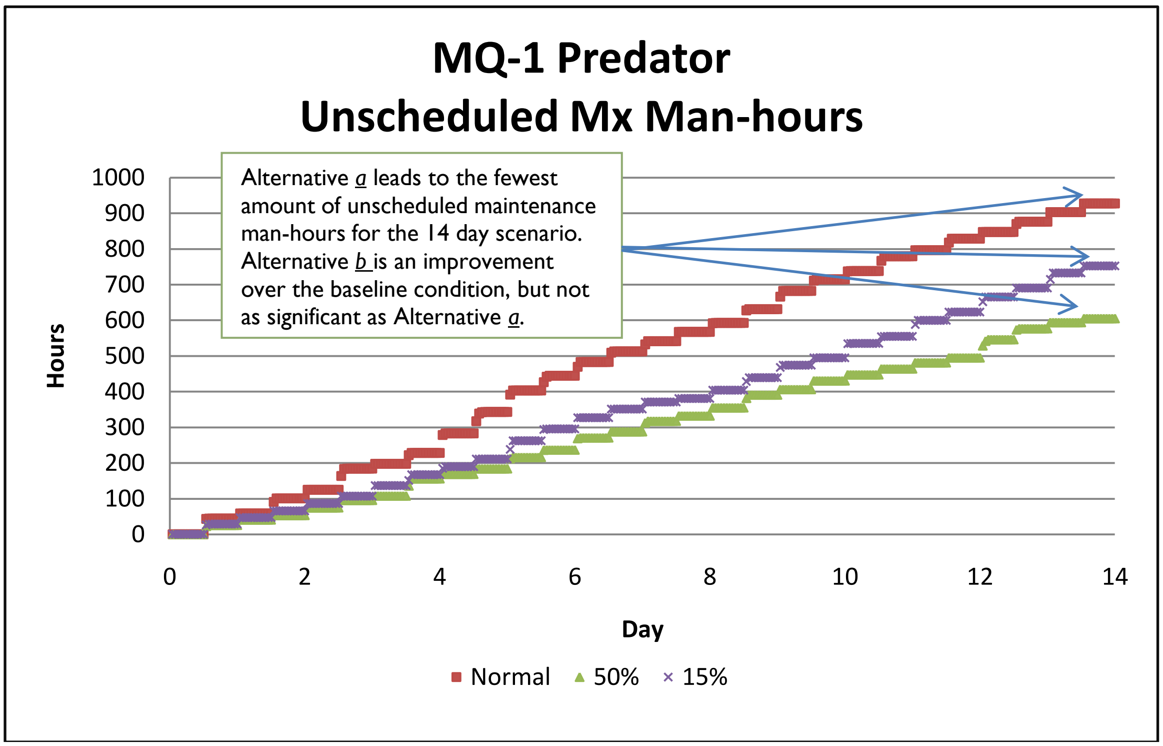
Environment, primary safety, and primary occupational health hazards are reduced by 1 interaction by removing the oil servicing of the 25 hour engine inspection.

| | Environment | Safety Primary | Safety Secondary | Occ Health Primary | Occ Health Secondary |
|---|---|---|---|---|---|
| 25 Hour Engine - Oil Servicing | 2 | 13 | 1 | 8 | 4 |
| 25 Hour Engine - No Oil Servicing | 1 | 12 | 1 | 7 | 4 |

**Notional table of the MQ-9 Reaper ESOH interactions contrasting the normal versus modified requirements of the 25 hour engine inspection. Primary interactions occur when a maintainer deals directly with an unsafe condition (e.g. loading munitions, hot oil temperature). Secondary interactions occur when a maintainer is in the near vicinity of an unsafe condition (e.g. loud engine noise).**

**A: Yes. By removing the oil servicing requirement of the 25 hour engine inspection, the maintainer has fewer interactions with environment, safety, occupational health hazards and less oil is introduced to the environment. The feasibility of waiting until the 60 hour engine inspection would have to be approved by the engine manufacturer. Cost savings with reduced need for oil and manpower may also be realized.**

**Q: If I had to choose between *a*) improving my 10 least reliable components by reducing the time it takes to repair them by 50% or *b*) improving my 50 least reliable by 15%, what alternative would give me the better return on investment?**

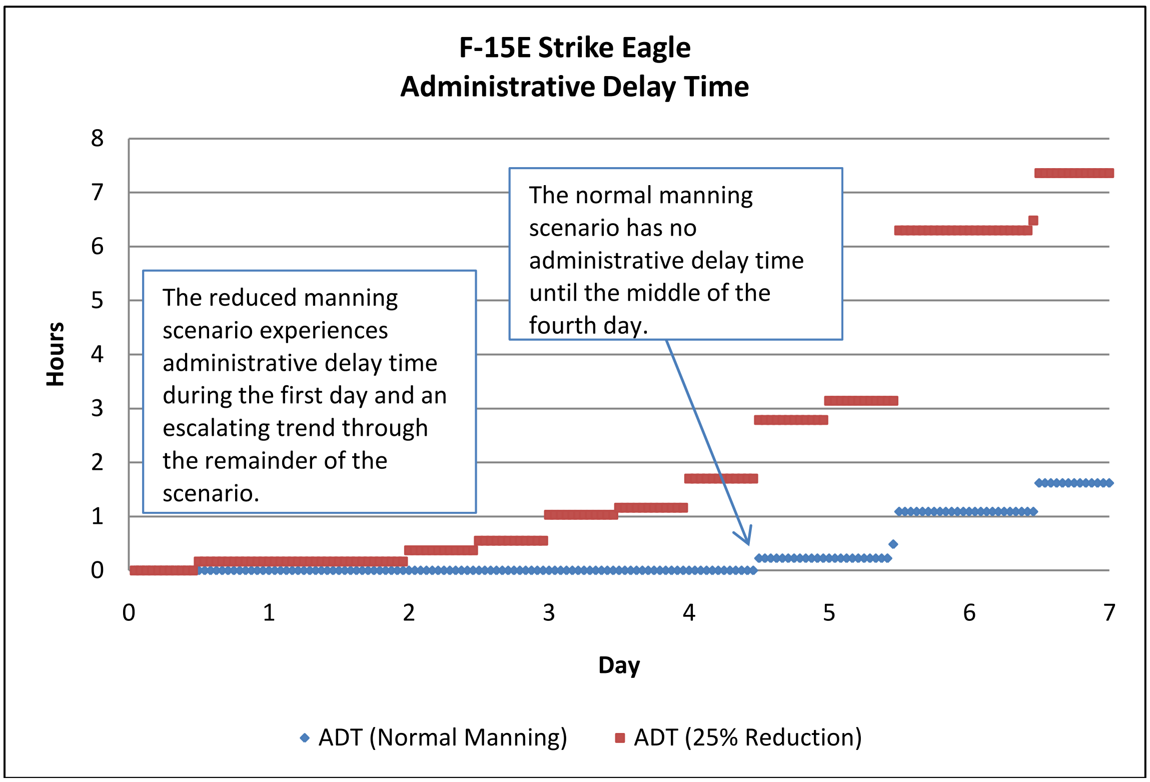



**Notional chart of the MQ-1 Predator maintenance man-hours required to support a 14 day scenario contrasting the normal reliability and maintainability with two improved alternatives. One alternative is a 50% decrease in the maintenance time for the 10 least reliable components. The second alternative is a 15% decrease in the maintenance time for the 50 least reliable components.**

**A: If all things are constant, investing in alternative *a* is a better option than *b*. Alternative *a* provides a 35% improvement over the baseline scenario (605 vs. 927 man-hours). Alternative *b* provides a 19% improvement over the baseline scenario (752 vs. 927 man-hours).**

## Q: Will administrative delay time be worse if I decrease the amount of available manpower by 25%?

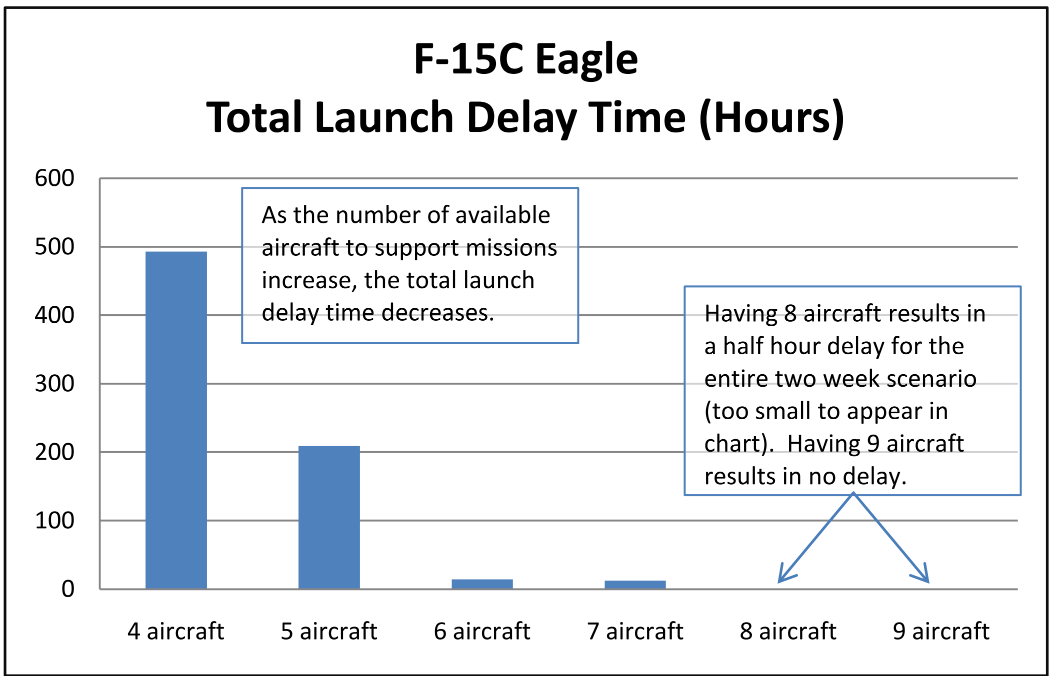
**(Future Possibility: Will reducing the administrative support of the flightline maintenance team impact sortie generation rate?**




**Notional chart of the F-15E Strike Eagle administrative delay time contrasting a normal manning scenario with a reduced manning scenario. Administrative delay time captures the total time that all aircraft needing unscheduled maintenance wait until available manpower can perform the corrective repairs.**

**A: Yes. Administrative delay time is increased when reducing the amount of available manpower by 25%. In this example, a 25% reduction of available manpower increases administrative delay time from 1.5 hours to 7.25 hours for a 7 day scenario.**

**"What is the minimum number of weapon systems needed to meet the requirements of the flying schedule without any delayed launch times (i.e. 100% Flying Schedule Effectiveness)?**




**Notional chart for the F-15C Eagle showing the total launch delay time in hours for a one week scenario with six 3 hour missions per day (42 missions in total).**

**A: 9 aircraft is the minimum number of weapon systems needed to meet the requirements of a 42 mission flying schedule (6 3-hour missions per day for 7 days) without any delayed launches. Having 8 aircraft nearly met the requirements but failed when one launch was delayed by a half hour.**

## How does the USAF HSI Maintenance Model answer all things HSI?

How many environmental interactions and mishaps can be eliminated?

Are there enough maintainers to fulfill the mission?

What is the optimal mix of specialties for mission success?

Can munitions installations and downloads be modified to reduce casualties without impacting readiness?


How frequently should training be conducted and on what skills to avoid skill decay?

How will mission capability improve if the maintainer is given a suitable environment to sleep and avoid fatigue?

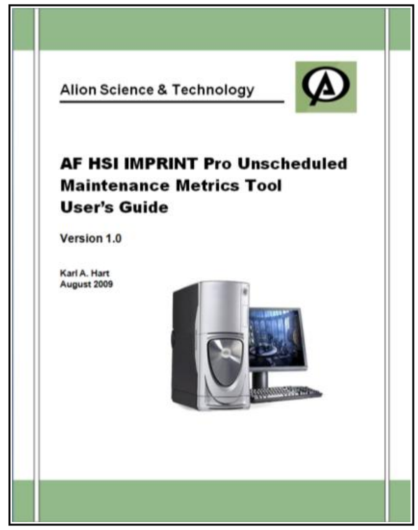
Can improving the design of maintainer interfaces with the aircraft increase weapon system availability?

How many occupational health interactions and mishaps can be eliminated?

How many safety interactions and mishaps can be eliminated?

**Project History:** The origin of this project began in October of 2007 when the 711th HPW awarded an advisory and assistance services contract for investigating Human Systems Integration in Air Force major command operational metrics. From October 2007 through September 2008, the 711th and Alion Science and Technology designed a human performance simulation of the F-15C Eagle that lay the groundwork for the current evolution of the simulation. Since September 2008, the team has expanded the simulation to include five new weapon systems and many more predictive and user interface capabilities.

## 7.8 AF HSI IMPRINT Pro Unscheduled Maintenance Metrics Tool User's Guide




The user's guide for the AF HSI IMPRINT Pro Unscheduled Maintenance Metrics Tool describes how to:

1) Install the tool onto the user's computer
2) Start and close the tool
3) Run the tool. This concludes with a dataset consisting of USAF unscheduled maintenance metrics being exported to a Microsoft Excel file.
4) Append the tool's existing data.

Installing and running the tool are simple – no installation wizard is required. This tool is comprised of two pieces: the "front end," which consists of the user interface, and the "back end," which contains the datasets for each of the weapon systems. These datasets include maintenance data, flight hour data, and work unit code descriptions. To operate the tool, both the front end and the back end must be copied to the user's computer and in the same directory.

For further guidance on the installation and operation of the AF HSI IMPRINT Pro Unscheduled Maintenance Metrics Tool, the user is encouraged to read its user's guide.

# 8 BIBLIOGRAPHY

85th Group Instruction 21-206, Fighter Maintenance Alert Procedures, 17 February 2004.

374th Airlift Wing Instruction 36-2201, Aircraft Maintenance Training, 24 March 2004.

908th Airlift Wing Instruction 21-101, Enroute Maintenance Support, 23 June 2003.

Air Force Doctrine Document 1, Air Force Basic Doctrine, 17 November 2003.

Air Force Doctrine Document 1-1, Air Force Task List, 12 August 1998.

Air Force Doctrine Document 2, Employment of Aerospace Power, 17 February 2000.

Air Force Doctrine Document 2-4, Combat Support, 22 November 1999.

Air Force Doctrine Document 2-4.2, Health Services, DRAFT, August 2002.

Air Force Doctrine Document 2-4.2. “Health Services.” Microsoft PowerPoint.

Air Force Instruction 10-601, Capabilities-Based Requirements Development, 31 July 2006.

Air Force Instruction 21-101, Aircraft and Equipment Maintenance Management, 29 June 2006.

Air Force Instruction 63-1201, Life Cycle Systems Engineering, 23 July 2007.

Air Force Logistics Management Agency, LCOM Process Reengineering, AFLMA Final Report LM200528500, June 2006.

Air Force Officer Classification Directory, The Official Guide to the Air Force Officer Classification Codes, 31 January 2008.

Air Force Performance Plan Annex, Performance Measure Details, February 1999.

Air Force Space Command Instruction 21-165, Aircraft Flying and Maintenance Scheduling Procedures, 1 October 2004.

Air Force Strategic Plan Volume 2 Performance Plan, February 1999.

Air Force. United States Air Force, Headquarters Air Combat Command. Environment, Safety, Occupational Health Training Symposium. Langley Air Force Base, Virginia: 2008.

Black, M., Daily D., Smith K., and Tatum J. "Eagle Plus Air Superiority into the 21st Century." April 1996.

Career Field and Education Training Plan 2A3X3, Parts I and II, Fighter Aircraft Maintenance Specialty Crew Chief, 1 February 2007.

Career Field and Education Training Plan 2M0X2, Missile and Space Systems Maintenance, 1 October 2005.

Chairman of the Joint Chiefs of Staff Instruction 3170.01F, Joint Capabilities Integration and Development System, 1 May 2007.

Chairman of the Joint Chiefs of Staff Manual 3170.01C, Operation of the Joint Capabilities Integration and Development System, 1 May 2007.

Department of Defense Instruction (DODI) 5000.1, Defense Acquisition System, 12 May 2003.

Department of Defense, MIL-STD 882D, Standard Practice for System Safety, 10 February 2000.

Defense Acquisition Guidebook, November 2004.

Gulf War Air Power Survey, Volume III, Logistics and Support, 1993.

Harris, J. "The Sortie Generation Rate Model". Air Force Studies and Analyses Agency.

Joint Chiefs of Staff Capabilities-Based Assessment User's Guide Version 2, Force Structure, Resources, and Assessments Directorate, December 2006.

TO 00-20-2, Maintenance Data Documentation, 15 April 2007

# 9 LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

| | |
|---|---|
| 711 HPW/HP | 711 Human Performance Wing/Human Performance Directorate |
| A&AS | Advisory and Assistance Services |
| ABDR | Aircraft Battle Damage Repair |
| AF | Air Force |
| AFB | Air Force Base |
| ARL | Army Research Laboratory |
| BPO/PR | Basic Post-flight/Preflight Inspection |
| C/C | Contingency/Combat Inspection |
| CONOPS | Concept of Operations |
| DoD | Department of Defense |
| DTIC | Defense Technical Information Center |
| EOR | End of Runway |
| ESOH | Environment, Safety, and Occupational Health |
| FMC | Fully Mission Capable |
| GUI | Graphical User Interface |
| HPO | Hourly Post Flight Inspection |
| HSI | Human Systems Integration |
| IMPRINT Pro | Improved Performance Research Integration Tool Pro |
| MAJCOM | Major Command |
| MDCS | Maintenance Data Collection System |
| MECR | Mean Event Crew Ratio |
| MET | Mean Event Time |
| MSgt | Master Sergeant |
| MSIAC | Modeling and Simulation Information Analysis Center |
| MTBME | Mean Time between Maintenance Events |
| MXG | Maintenance Squadron Group |
| NTIS | National Technical Information Services |
| OPSTEMPO | Operational Tempo |
| PE | Periodic Inspection |
| PDM | Programmed Depot Maintenance |
| PR/BPO | Pre-flight/Basic post-flight Inspection |
| PR | Pre-flight Inspection |
| QT | Quick Turn Inspection |
| SAFTE | Sleep Activity Fatigue Task Effectiveness |
| SME | Subject Matter Expert |
| WUC | Work Unit Code |